

Data management for integrated water resources management in Central Asia

Iskandar Abdullaev and Shavkat Rakhmatullaev

ABSTRACT

Information technologies can act as technical artifacts and can facilitate stakeholder communication, supporting decision making in a complex societal context. The water sector is one such example where limited water resources are threatened by climate change and growing competition for resources between sectors, regions and countries. Attempts to improve water governance and management through information technologies have been made by international, regional and national water agencies for the last 20 years in Central Asia. However, early attempts were focused on collection, systematization and analysis of the generic data related to the water sector in the region. There are still significant gaps (technical, human and financial capacities) for application of such technologies at the lower operational levels of water management, i.e. where the full dimensions of variables, interactions and complexities are observed and, most importantly, everyday politics of water are performed. The aim of this paper is to present practical results on improving water management in Central Asia through the application of better data management tools at the operational level across diverse institutional settings, i.e. transboundary, watershed levels in the region.

Key words | data management, database, geographical information system, operational level, remote sensing, transboundary water management

Iskandar Abdullaev

The Regional Environmental Centre for Central Asia (CAREC),
40, Orbita-1 Street,
050043,
Almaty,
Kazakhstan

Shavkat Rakhmatullaev (corresponding author)

Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH,
Transboundary Water Management in Central Asia Programme,
7A Chimketskaya Street,
100029,
Tashkent,
Uzbekistan
E-mail: rakhmatullaev@rambler.ru

INTRODUCTION

After the disintegration of the former Soviet Union, new independent states of Central Asia, namely Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan and Uzbekistan, have witnessed transformations of political, economic and social systems. Economic transition from centralized, planned economies to more market-like policies have resulted and introduced 'new' concepts like land tenure, water rights and different kinds of land ownership (Abdullaev & Mollinga 2010; Rakhmatullaev *et al.* 2010b). The institutional changes included decentralization of the agricultural production systems, i.e. a transition from the former state and collective farms to the smaller forms of public or private farming. These changes have also been translated into the water sector, situating it into the new political and socio-economic arrangements (UNDP 2005; Abdullaev *et al.* 2010).

At the river basin/watershed level, water management has been transformed from the previous territorial management (administrative) into the hydrographic units in the three countries with still on-going efforts in Tajikistan and Turkmenistan (Yalcin & Mollinga 2007; Abdullaev & Atabaeva 2012). At the local level, water user associations have been formed at the on-farm level (Yakubov & Ul Hassan 2007; Abdullaev *et al.* 2009). In fact, agriculture uses about 90% of water resources of the region for irrigation (WB 2003; UNEP 2005; Sokolov 2006; Dukhovny 2007).

These political, economic and social changes have increased the flow of information and the number of stakeholders involved in the decision-making process on water management and the transformed water governance framework (Abdullaev & Rakhmatullaev 2011, 2012). The contemporary situation with full involvement of different

stakeholders requires that open source, easy to access information and user-friendly data management systems are in place. However, at present the data and information on the water sector are often dispersed, heterogeneous, incomplete, and not comparable (GWP & INBO 2009; Abdullaev *et al.* 2012).

The greatest challenge is a practical implementation of activities at the lowest water management level – known as operational (Garcia 2008). At this level the full dimensions of variables, interactions and complexities are observed where everyday politics of water are conducted (Mollinga 2008; Abdullaev & Mollinga 2010; Abdullaev *et al.* 2012). In the case of Central Asian states, where water management is still mostly state business, the operational level includes district and provincial water management organizations (WMO) (Abdullaev 2011; Abdullaev & Atabaeva 2012). The data management in this level will help to address most of the water governance issues, such as transparency of decision making (defining water rights or limits) on water distribution and water control, involvement of the water users in water management and supporting comprehensive river basin planning.

Interactions and interdependencies among various actors, both human and non-human are shaping decision-

making processes in the water sector (Abbott & Jonoski 2001). The everyday politics of water could be described through the application of main principles in an actor-oriented approach (Long 2001). According to Long, ‘... upon the capacity of actors to process their and others experiences and act upon them’. Actors that are engaged in the everyday politics of water management could be divided into six categories: (i) water users; (ii) state bodies; (iii) irrigation and drainage infrastructure; (iv) natural environment; (v) social environment; and (vi) information communication technologies (ICTs) (Figure 1). More access to water information and data for both policy makers and the public will help to promote integrated water resources management (IWRM) principles, i.e. a participatory approach (Michalski *et al.* 2001; Biswas 2008; McDonnell 2008; Garcia 2008; Biswas & Tortajada 2010; GWP 2011; Hoekstra 2011).

ICTs are acting both as technical artifacts and to facilitate more inclusive and transparent decision making (Curry 1999; UNDP 2008). ICTs have been employed in the water sector elsewhere in the world, under a variety of environmental conditions, levels of engineering complexity and socio-political arrangements, yet with differing levels of success (Choi *et al.* 2005; van Griensven *et al.* 2006; Wallace *et al.* 2006; Cesur 2007; Gaiser *et al.* 2008; Ozdogan

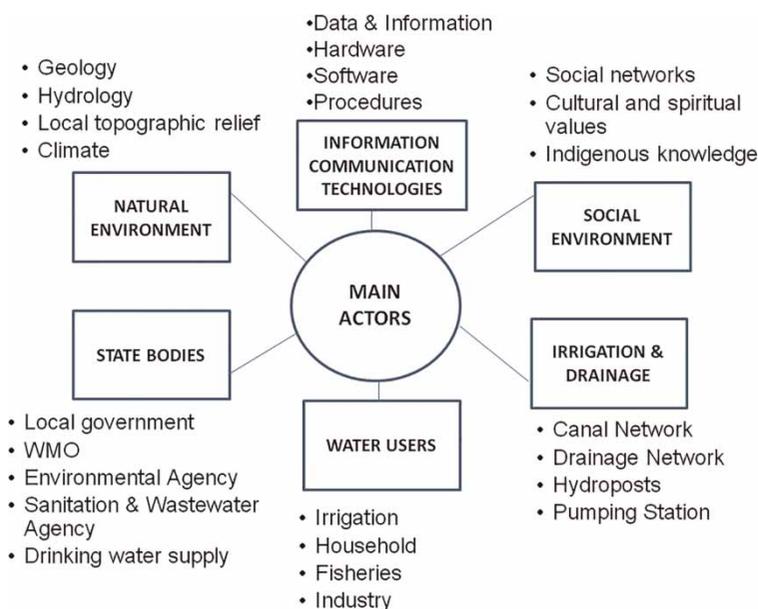


Figure 1 | Main actors of everyday water management (adapted from Abdullaev & Mollinga 2010).

et al. 2010; Thenkabail *et al.* 2010; Merem *et al.* 2011; Pechstädt *et al.* 2011; Puls 2011; Moody & van Ast 2012).

The purpose of this paper is to shed light on the implementation of information and data management systems, in practical considerations in the countries of Central Asia, at operational levels where day-to-day water matters are carried out. First, this paper provides a systematic overview of past projects and programs on the application of ICTs in the water sector of arid Central Asia and their shortfalls. Secondly, it complements practical actions in the selected sites under different institutional and environmental settings (transboundary, basin, and national levels of water management). Finally, it concludes with major findings and potential opportunities for improvements in data management at an operational water management level in the region. The case study presented is conducted within the framework of the Transboundary Water Management in the Central Asia program (the Transboundary Water Resources Management in the Central Asia (TWMCA) program is funded by the German Federal Foreign Office and implemented by Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH in five Central Asian countries).

APPLICATION OF ICT IN WATER SECTOR OF CENTRAL ASIA

Status quo of ICT in the region

The recent advances in ICTs and the push for e-government (or electronic government) worldwide made it possible to look into the problem of water management with a fresh perspective. E-Government is a digital platform for interactions between a government and citizens using ICT infrastructure in different aspects of their livelihoods and development. The e-government readiness index is an indicator for showing government readiness to use ICTs towards more inclusive and transparent government structures. More precisely, the e-government readiness index is 'a composite measurement of the capacity and willingness of countries to use e-government for ICT-led development' (UNDP 2008).

According to the study, the Central Asian region has made the most significant improvement in e-government development as a region, but is still slightly below the

world average (UNDESA 2011). The material evidence suggests that almost all Central Asian countries have made considerable progress (improvements in e-government readiness index (Table 1) and world e-government ranking) in the implementation of e-government steps. For example, all national water authorities of the region have their web sites (Table 2). According to the UN indicator on e-government evolution, the development of ICT in the water sector of Central Asian states falls into stage II which is:

'Enhanced: Governments provide more information on public policy and governance. They have created links to archived information that is easily accessible to citizens, as for instance, documents, forms, reports, laws and regulations, and newsletters' (UNDP 2008).

However, the application of ICTs at the operational level is still very limited. Nevertheless, systematic framework conditions such as considerable improvements in physical and human skills, and unprecedented developments in infrastructure for wider adaptation of ICTs in the water sector of the region, allows for development of the more systematic information and data management settings.

Experience of data and information management systems

Data management has been one of the important functions of the WMOs at all levels during the Soviet period in Central

Table 1 | E-government readiness index and world ranking of Central Asian countries

Country	E-government readiness index ^a		World e-government development ranking		
	2008	2010	2008	2010	Change
Kazakhstan	0.4743	0.5578	81	46	+ 35
Kyrgyzstan	0.4195	0.4417	102	91	+ 11
Tajikistan	0.3150	0.3477	132	122	+ 10
Turkmenistan	0.3262	0.3226	128	130	-2
Uzbekistan	0.4057	0.4498	109	87	+ 22
World average	0.4406	0.4514	Total number of countries = 192		

^ae-government readiness index is composed of: (i) web measure index; (ii) telecommunication infrastructure index; (iii) human capital index.

Source: UNDESA 'e-Government Readiness Knowledge Base' (2011).

Table 2 | Summary of web site features of national water management authorities in Central Asia

Country	Website address	About ministry (organizational structure, relevant institutions)	News and events in water sector	Online feedback form or emails	Useful downloads (materials, reports, laws)	Links to subordinated WMOs
Kazakhstan	http://minagri.gov.kz	+	-	+	-	-
Kyrgyzstan	http://www.river-basins.kg	+	-	+	-	-
Tajikistan	http://www.mwr.tj/ru	+	+	+	+	-
Turkmenistan	http://www.minwater.gov.tm	+	-	+	+	-
Uzbekistan	http://www.agro.uz	+	+	+	-	-

Asia (Abdullaev & Rakhmatullaev 2012; Abdullaev *et al.* 2012). The data and information in the water sector have been handled hierarchically through an administrative reporting system: from the lowest WMOs towards the higher levels (national and regional). However, the numbers of reports produced by WMOs were large and mostly in formats which were not accessible or understandable for the general public. The WMOs were producing annual reports and storing them in the archives for at least 5 years. The data collected were submitted to the statistical departments of provincial government authorities, and annual statistics books were published as the source of the data and information.

In Central Asia, since the mid-1990s regional water management authorities such as the Scientific Information Center of Interstate Commission for Water Coordination (SIC ICWC), the International Funds for Saving Aral Sea through technical and financial support from international and national partners, have been trying with varying success to implement data management improvements in the water sector. The activities were targeted on the generation, collection and application of modern tools (Geographic Information Systems (GIS), Remote Sensing (RS), Decision Support System and models, etc.) in water management at different levels. The data management activities during the mentioned period cover different levels, aspects, and regions of Central Asia on water management (Table 3) (Cawater-Info Web 2011).

Most of the projects listed in Table 3 have produced the data and information which are of restricted access and contain retrospective data sets. In addition, the primary target levels of the above interventions were regional or national levels of water hierarchy. Yet, the databases reflect only retrospective data for countries on the general situation of the water sector (descriptive nature) without fully operational

datasets, i.e. which are the primary sources for further analysis, modeling and scenario developments of the river basins.

In summarizing the current situation analysis in the region, the authors conclude that limited success of ICTs application in the water sector of the Central Asian countries could be attributed to the following three broad categories: (i) hesitance of the WMOs to allow public access to crucial operational information; (ii) insufficient capacities (knowledge and technical) of the WMOs; and (iii) the turnkey fashion of implemented activities (by donor communities) without involvement of partner WMOs. Therefore, tedious manual data management practices persist in the everyday operation of WMOs as the main tool to gather, store and report the information (Abdullaev & Rakhmatullaev 2011).

Study areas

Within the framework of TWMCA program, seven pilot areas have been selected in consultation with partners from WMOs as intervention sites for the data management activities (Figure 2). The selected sites could be divided into two distinguishable types: (a) transboundary sites with two or more countries sharing water resources (Pilot area No. 3 – Isfara in Figure 2) and (b) sites within national border (Table 4).

MATERIALS AND METHODS

Conceptual framework and strategic approach

The long-term sustainable water management in Central Asia could be reached by preparation of long-term river basin management plans by WMOs. Therefore, the ultimate

Table 3 | Water management databases and information systems sponsored by the international development agencies in Central Asia

Database	Project/donor	Level of data collection	Source or link and data accessibility	Relevance to the water governance
Water Management Information System (WARMIS)	Water Resources Management and Agricultural Production (WARMAP) project, European Union	Six themes such as water, water quality, economy, administration, etc. The data is attributed into provinces, districts of five Central Asian states	No access, PowerPoint presentation is available at www.cawater-info.net/careweis/warmis_e.htm	It reflects only the situation for the selected sites and time series on which data has been collected. Mostly retrospective data, access to the data is limited and publicly not available
Water Use and Farm Management (WUFMAS)	WARMAP project phase 2, European Union	Total of 91 farms in 1996–1999, located in the five republics in the Aral Sea basin	No access, PowerPoint presentation is available at www.cawater-info.net/careweis/wufmas_e.htm	It reflects only the situation for the selected farms and time series on which data has been collected. Mostly retrospective data, access to the data is limited and publicly not available
Copernicus database	European Union	Selected households, and on field operations	No access, PowerPoint presentation is available at www.cawater-info.net/careweis/copernicus_e.htm	It reflects only the situation for the selected households and fields and time series on which data has been collected. Mostly retrospective data, access to the data is limited and publicly not available
River Twin Project database	European Union	Chirchik-Akhangaran-Keles sub basin	No access	It reflects only situation for the selected basin. Data access is limited and publicly not available
Central Asia Regional Water Information Base (CAREWIB)	Swiss Development Cooperation, European Union, German International Cooperation	Region, states of Central Asia, main river basins	Partial access through online registration www.cawater-info.net . The registration have to be approved by Project Management	It is a very useful and important tool for analysis and research. Main shortcoming is absence of operational data on water management
Water in Central Asia' (CAWa) database	German Federal Office	Region, selected provinces, irrigation systems	Partial access www.cawa-project.net/	

Source: Cawater-info.net web portal (2011).

goal of the data management activities of the TWMC program was to provide both human and technical capacities, with tools on data management for WMOs at an operational level enabling them to improve decision-making processes in the water sector.

The core of the data management concept is in improving the collection, systematization and use of the data for

long-term basin planning (Figure 3). Data management interventions have been designed from the bottom up, with full involvement of the partner WMOs in the activities from the very beginning, pre-assessment and planning stages. Therefore, experts of partner WMOs have greatly contributed to the selection of the type, structure, content, interface and format of the data management tools, creating

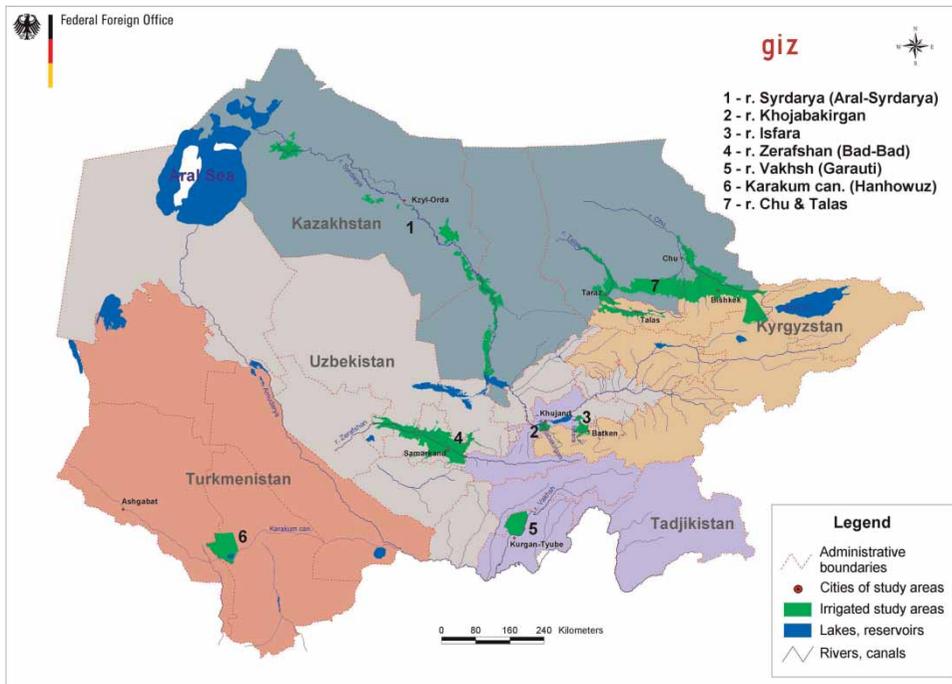


Figure 2 | Location of pilot irrigation and river basins areas in Central Asia.

Table 4 | Characteristics of water management organizations at the intervention sites

Country	Area of interest	Partner organization	Level
Kazakhstan	Aral-Syrdarya River Basin	Aral-Syrdarya Basin Inspection Authority	National
	Chu-Talas River Basins	Kazakh-Kyrgyz Joint River Basin Commission on Chu-Talas Rivers	Transboundary
Kyrgyzstan	Kyrgyz part of Isfara and Khodja-Bakirgan River Basins	Batken Basin Water Management Administration	Transboundary
	Isfara River Basin	Batken Basin Water Management Administration	National
	Chu-Talas basins	Kazakh-Kyrgyz Joint River Basin Commission on Chu-Talas Rivers	Transboundary
Tadjikistan	Tajik part of Isfara and Khodja-Bakirgan River Basins	Sogd Province Water and Melioration Authority	Transboundary
	Isfara River Basin	Sogd Province Water and Melioration Authority	National
	Garauti Irrigation System	Khalton Province Water and Melioration Authority	National
Turkmenistan	Hanhowuz Irrigation Scheme	Karakum Canal Administration	National
Uzbekistan	Zerafshan River Basin	Zerafshan Basin Irrigation Systems Authority	Inter-provincial/ National

clear ownership of the process by partner WMOs. The strategic approach applied in this intervention is the generation of political support for data management from national water agencies of partner countries. Only goodwill and readiness to accept data management tools for water management can make interventions successful.

Needs assessment and capacity building

At the initial steps of the intervention, comprehensive pre-assessment of hardware and capacity-building needs of local WMOs on data management have been carried out through surveys and interviews with key players of local

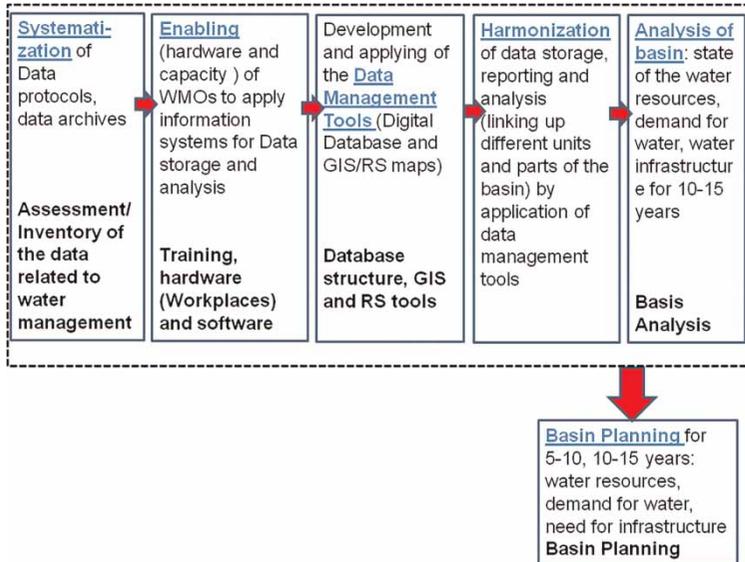


Figure 3 | Logical framework of data management activities for river basin planning.

WMOs, i.e. administrative and technical staff. Based on the results of this assessment, partners were provided with up-to-date hardware and software for data management (collection, storage and processing). Data management workspaces were established in each location. The workspaces have been connected with various units of the WMOs, dispatch centers, water planning units and other relevant departments through local networks and internet connections. This effort has helped to improve accessibility, operation of the data management tools, and data entry.

Strong efforts were made to create and support individual human capacities within partner WMOs on data management such as Internet Basics, GIS, Global Positioning Systems (GPS), and RS. The partner WMOs have nominated one or two water professionals involved in daily data handling and one expert from local research organizations/universities (outside of WMOs) into the capacity building events.

Data management tools

At present, integrated, multi-purpose and sophisticated GIS-based data management tools are available for water resources management (Pickles 1995, 1999; Moody & van Ast 2012). However, knowing the capacity limitations of

partner WMOs, the TWMCA program helped to develop two types of data management tools: digital database and GIS-based irrigated area maps.

The 'Database' has been designed to store and use digital data on water resources, water use, hydraulic facilities, hydrological settings, economic, and administrative conditions of the location such as basin and irrigation system. The database has been developed using open-source hypertext preprocessor script language, and is at present commonly used for web-based databases (PHP 2011). The foundation platform was MySQL[®] which is a freely downloadable version of the world's most popular open source database (MySQL 2011). It is especially suited for web development and can be embedded into hypertext markup language.

The use of the PHP language makes it easy to launch an internet-based version of the database, which provides wider access to the database for water professionals, policy makers, academics and the general public. This program language allows the insertion of additional tables and updating of the database by trained experts of WMOs without the aid of a programming specialist. The datasets listed in the database are at present regularly collected by WMOs and are available in different formats (MS Excel, Word, Access etc.), and can be loaded into the database by import/export commands or manual typing.

GIS and RS tools are widely used around the world to assess, plan and manage water resources, irrigated areas, and crop development (Bastiaanssen 1998; Ozdogan *et al.* 2010; Thenkabail *et al.* 2010; Moody & van Ast 2012). Remotely-sensed satellite images, digital elevation models (DEMs), different map layers and geographical coordinates of water infrastructure recorded by GPS receivers are used for water resources management.

Application of the GIS and RS tools to assess size and location of the irrigated areas is a most important contribution to improve water resources management planning and allocation in Central Asia, where irrigation contributes up to 90% of water use from transboundary rivers (Chemin *et al.* 2003, 2005; Fortes *et al.* 2005; Conrad *et al.* 2007, 2010; Platonov *et al.* 2008; Rakhmatullaev *et al.* 2010a; Mergili & Schneider 2011; Pereira-Cardenal *et al.* 2011; Kariyeva & van Leeuwen 2011). In this intervention, land use and land cover maps (LULC) are produced for each location. ArcGIS 9.3.1® was used for preparation of raster and vector layers and ERDAS Imagine® was used for satellite image processing.

Institutional aspects of data management

Successful data management intervention depends on how well it is integrated into the regular, daily practices of WMOs (Tortajada 2010). There are many cases of shortfalls of ICTs application into the water sector around the world (Cesur 2007; Eludoyin *et al.* 2007; Ozdogan *et al.* 2010; Pereira-Cardenal *et al.* 2011). Therefore, interventions on data management have been focusing on the development and implementation of the database system architecture that fully satisfies the needs of the WMOs in terms of content, format, and interface. Algorithms for reporting on daily water information have been provided by WMOs that helped to develop the analytical reporting section of the database. This was done in order to produce compulsory reports automatically, i.e. helped to reduce the workload of the WMOs and improve efficiency in data systematization. Both database interfaces and user manuals were prepared in local languages in order to make easy use of the database and GIS tools.

To support the dissemination and replication of the data management activities to other basins and irrigation

systems, the working groups were established at the national level in each country. The working groups are composed of deputy heads of the provincial WMOs, who are experts of water agencies responsible for water planning and information management. In the process of implementation of the project it was revealed that within the water management hierarchy there is inconsistency and shortcomings on data management. Therefore, unexpected intervention was launched additionally at the national level, focusing on systematization of procedures, roles and responsibilities for efficient management of information and data in the water sector.

At a transboundary level, joint working expert groups between Kyrgyz and Tajik national WMOs were established in one of the selected sites (Isfara). Regular coordination meetings have been carried out in order to exchange progress and harmonize data management activities. The coordination meetings were facilitated and supported by both the TWMCA team and recruited professional consultants. The rest of this paper will present practical results on data management from basin and transboundary perspectives.

RESULTS AND DISCUSSION

In Central Asia, improvements in water governance are part of the solution to the water problems (Aminova & Abdullaev 2009). This is especially true for the transboundary basins of Central Asia where climate change impact will bring more uncertainty and water shortages (IPCC 2007). Therefore, improving the transparency of water management through the application of data and information tools could be seen as a path towards more sustainable water resources management.

The results of data management activities, with qualitative impact indicators, across the Central Asian countries are presented in Table 5. The most promising signal was strong political support from the national water authorities of Kyrgyzstan, Uzbekistan, Tajikistan and Turkmenistan, which have issued support letters to the program indicating their desire to support the data management activities. In four of the above mentioned countries, special decrees were issued by the respective national water authorities declaring

Table 5 | List of main indicators (impact) on data management activities in the pilot areas of the TWMP CA program

Indicator	Political support	Database system	Access to data and information	GIS/RS maps	Application status	Follow ups by partners
Kazakhstan	+	n/a	n/a	+	n/a	n/a
Kyrgyzstan	+	+	+	+	+	+
Tajikistan	+	+/-	+/-	+	-	+/-
Turkmenistan	+	n/a	-	+	+/-	+/-
Uzbekistan	+	+	+	+	+	+

+ (positive progress); - (no progress); +/- (mixed progress); n/a – no comment.

the use of the database as the main tool for reporting within their respective national water hierarchical systems. In Kazakhstan, the national government is funding the national program on data management in the water sector.

Basin level

Database system

Former water datasets were created in MS Excel or MS Access formats, were accessible only to a limited number of users and were transformed into the web-based, user-friendly and easy functioning database with a menu of genuine components in all sites (Figure 4). The Help menu has been built into the database interface with manuals of database, GPS and satellite imagery in the Russian language, to make data management tools available for wider group of users and stakeholders.

Access to data and information

Access to the database has been one of the critical aspects of the data management. Partner WMOs were not eager and ready to immediately share data with ‘outsiders’ – organizations, i.e. people who are not working in the water sector. One out of seven WMOs have agreed during the initial meetings to post a database online. However, even this WMO did not want to give free access to the database, and has limited the access by introducing user names and passwords for the data users. Thus, in order to address this critical issue, the database has been designed with an administration menu incorporated into the main menu. This allows a WMO database operator to produce passwords and user names, extent list of data,

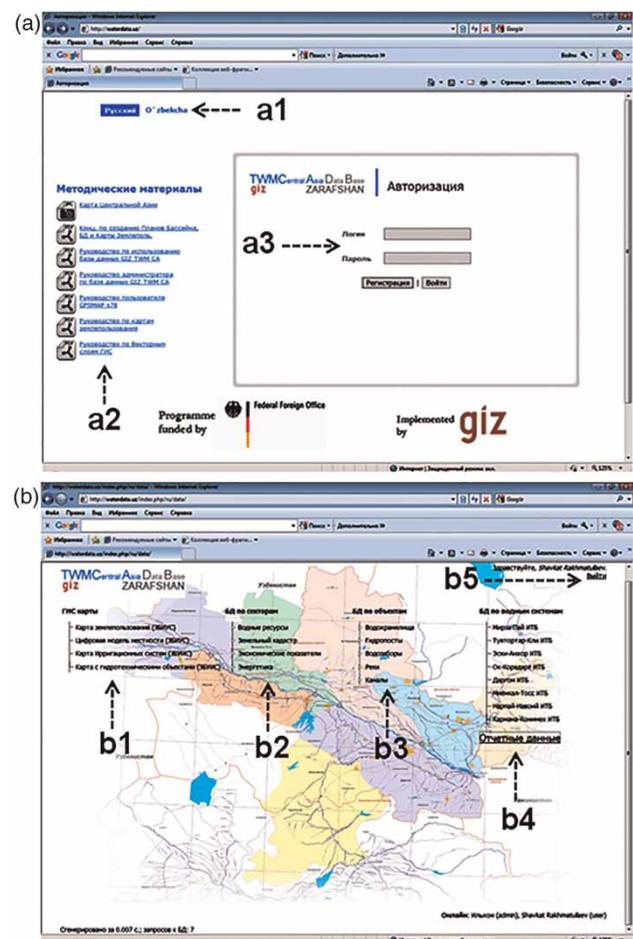


Figure 4 | Interface and architecture of database. (a) Interface of main page of database; a1 – Language versions; a2 – Help menu; a3 – Login and password; (b) Architecture of database; b1 – GIS based maps; b2 – Dataset of sectors; b3 – Dataset of hydraulic infrastructure; b4 – Reporting forms and protocols; b5 – Administration and management menu.

and add new sections into the database. In other words, the database can be updated without external intervention or support if WMOs would like to include new data sets into the database.

The absence of IWRM institutions, to facilitate effective coordinate and cooperation of both different agencies and stakeholders, makes data and information exchange a challenge worldwide (Schmeier 2011). A few discussions of the meetings were conducted with partner WMOs in order to present positive aspects of the information and data sharing for the water sector. After a few rounds of such meetings, other WMOs agreed to launch an internet database with the provision of access only to their staff from branches/units. Therefore, access to the databases is currently restricted to only the staff of respective WMOs. This allows the central server (dispatch center) operator to provide online data entry from the different units of the WMO. In addition, the databases are functioning as pilot tests within single WMOs.

GIS and RS maps

Professional experts from International Water Management Institute (IWMI) have been recruited to produce land use – LULC which are open source satellite images for the above described selected sites. The Landsat-5 satellite images were downloaded from the Internet (<http://glovis.usgs.gov/>) for the peak of the growing season (July–September) of 2009. The processing of the images has been completed by IWMI experts with on-the-job training for staff of the WMOs. On the other hand, WMO experts have collected and digitized different maps for GIS layers of irrigated areas such as topographic maps, administrative borders, irrigation system borders, etc. (Figure 5). The maps were manually digitized, using Landsat satellite images as the background layer.

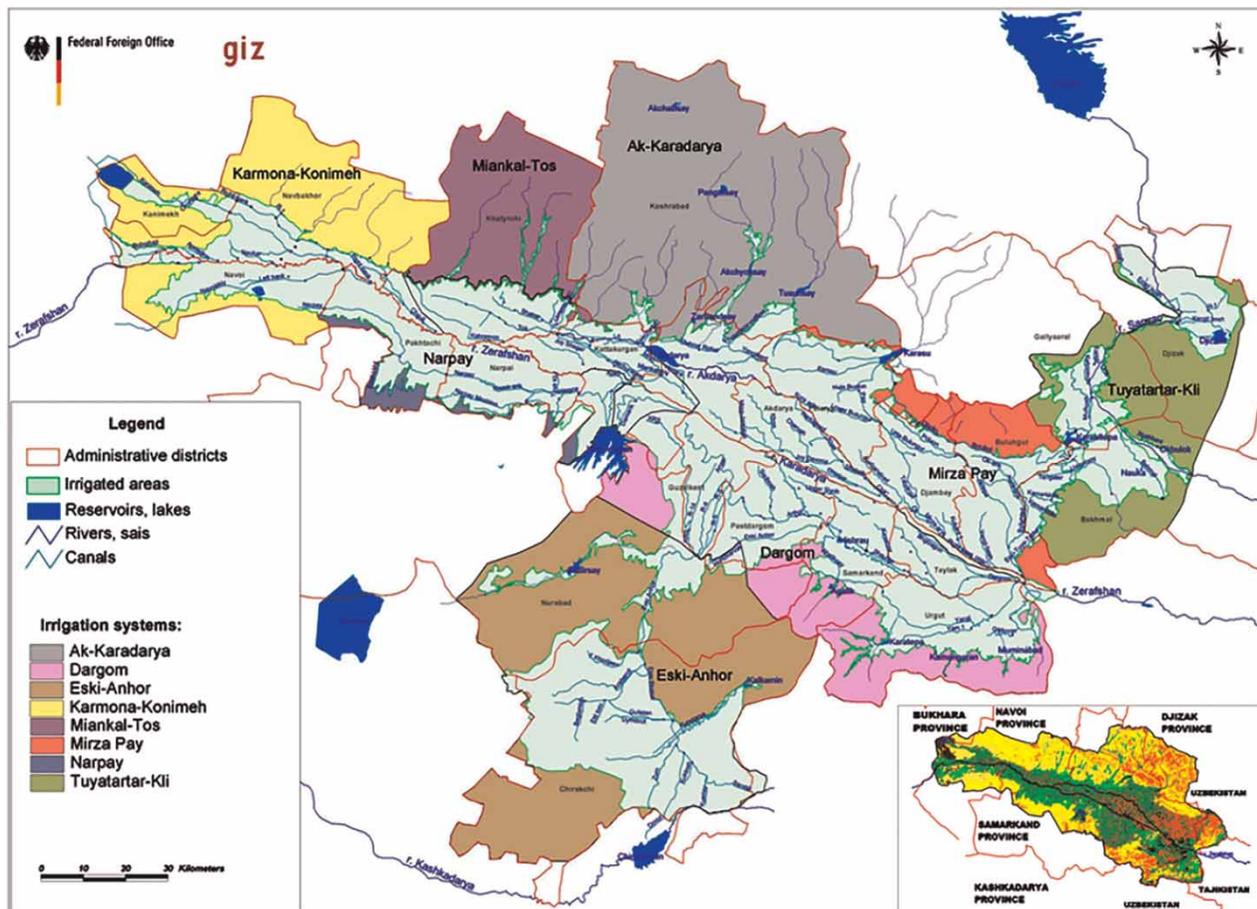


Figure 5 | GIS map of hydraulic infrastructure and irrigation districts of the Serafshan River Basin (Uzbekistan part).

For the delineation of basin boundaries at high altitudes, the publicly available Aster DEM with a spatial resolution of 30 meters were downloaded from the Internet (<https://wist.echo.nasa.gov>) for all intervention areas. The basin boundaries at low altitudes were further corrected with the use of the water infrastructure locations (ground GPS measurements). Further, the free products (MOD13Q1) created from MODIS satellite images, which represent the Normalized Difference Vegetation Index (NDVI) values (with spatial resolution 250 m and temporal resolution 16 days), were downloaded from the Internet (<http://glovis.usgs.gov/>). NDVI indices were used to identify land use classes. In the situation where the number of land use/land cover classes inside the study areas was unknown, an unsupervised classification with 16 classes of land use was applied separately to images of each study area (Figure 6).

GIS and RS tools differ from the database due to quite high requirements for the experts who will work with these tools. Without special training and long-term experience, local experts cannot produce GIS tools. However, LULC maps are not required to be prepared for each season or year, but rather updating it every 4–5 years will be sufficient for basin assessment and planning purposes. Keeping a professional staff with GIS skills is not feasible

in current conditions due to the low wages of WMO staff. Therefore, recruitment of a growing number of companies or GIS experts is an option for updating the LULC maps. However, in a few Central Asian states, national water authorities are starting to set up GIS units at the national level which can help WMO to produce LULC on a regular basis.

Application status and follow ups

The application of databases for everyday operations has shown various/mixed results across the pilot areas. For example, at present in Kyrgyzstan and Uzbekistan databases are filled with retrospective data for 2005–2011 and from 2012 the database has been used for day-to-day operations. In other pilot areas, it is unfortunate that databases are not fully used (Table 5). Some data turned out to be a difficult task to collect due to the loss of the paper reports which were stored in poor conditions at the offices of district (rayon) and provincial (oblast) WMOs. Although there has been an extensive capacity building component for the personnel of the partner WMOs, in the long-run the institutional learning is an important precondition for successful data management intervention. Presently, the internal structure of partner WMOs in all locations does not support institutional learning.

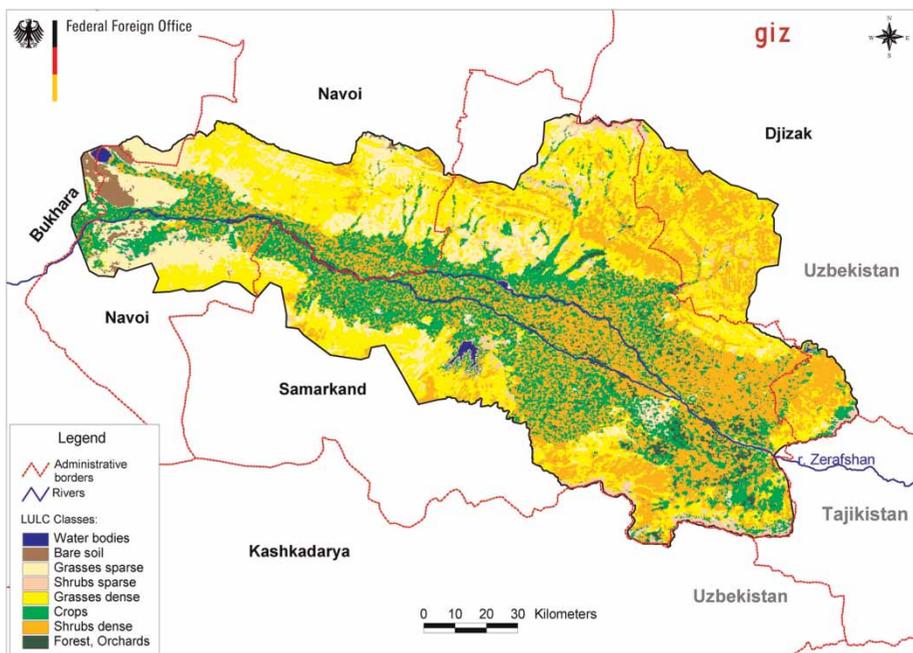


Figure 6 | Land use/Land cover classes of the Serafshan River Basin (Uzbekistan part).

Low wages, high turnouts and non-transparent promotion systems makes it difficult to keep highly qualified staff staying on with WMOs. Therefore, the danger that trained experts may leave soon after training was one of the concerns discussed with partner WMOs.

Risks/issues for knowledge management sustainability

In the beginning of project activities, the main concern was sustainability of generated knowledge within national WMOs. The potential risks/issues were jointly identified in a retrospective manner with national WMOs from the beginning of project activities, and the following mechanisms were agreed to be implemented. First, contract amendments were made by the national high level WMOs in at least three locations to both increase wages and insert specific incentive working conditions for trained staff in WMOs, after the completion of the project. Secondly, in other locations national WMOs have requested a TWMPA program to train more of their staff so that if one leaves then others could continue to operate the database.

Furthermore, in Kazakhstan and Turkmenistan (due to sufficient financial capacities), another advocated option was agreed upon to recruit local private contractors for updating GIS-based maps, because of 4–5 years needed for upgrading. In this case, an option was targeted to increase capacities of national WMOs for development of appropriate terms of references (ToR) for outsourcing the GIS-based works, indicating the specific needs in terms of content, technical specifications for hardware and software equipment. Most importantly, national WMOs were trained to explicitly incorporate in ToRs, a capacity building, elements with outsourced private contractors.

Another important observation was behavioral response for internal understanding and interpretation of data management activities from some involved individuals of national WMOs. In some cases the results were not fully accomplished, though in regular expert working group meetings, the TWMPA team has tried to re-direct the internal initiatives into the agreed channel of actions.

Transboundary level

Information and data sharing are an important part of the successful water governance in transboundary basins (GWP 2000; Grossmann 2005; Sadoff *et al.* 2008; Raadgever

et al. 2008). Therefore, developing information and data management systems for the operational levels of water resources management will help to pave a way for establishing viable conditions for IWRM development for riparian states on small transboundary basins of Central Asia (Abdullaev & Rakhmatullaev 2012).

One such example was carried out for the Isfara river basin between Kyrgyzstan and Tajikistan within the TWMPA. The strategy was to adapt a sub-basin approach (stepwise), i.e. implementation of parallel data management tools (database and GIS) for Kyrgyz and Tajik sub-basins according to their national water requirements. Yet, the main focus and argument was to design database systems with similar functionalities, modes, and structures, for compatibility in all locations. This was easily done due to the Soviet past of the WMOs, when data and information production had been standardized in the same manner for everywhere in Central Asia (Wegerich *et al.* 2011; Abdullaev 2011; Abdullaev & Atabaeva 2012).

The databases in different locations produce comparable reports which make future data and information exchange easy in the context of transboundary cooperation. Then, at the joint working group meetings, there has been dialogue to discuss ways for integrating transboundary aspects. Currently, it is premature status to practically implement transboundary databases between Kyrgyzstan and Tajikistan in the Isfara river basin due to an absence of joint river basin organization and interstate water agreement. However, the TWMPA has been supporting the efforts of two states for signature of interstate water agreement for almost 3 years.

For the GIS map, two separate sub-basin maps were created by Kyrgyz and Tajik teams, respectively. Yet there are many unresolved questions to merge the two parts into the single basin GIS map with administrative borders, hydro-technical infrastructures and Isfara watershed delineation due to trust-building of parties, unresolved country administrative border demarcation, and human capacities. In order to start up, discussion of a generic single DEM map for Isfara was presented (Figure 7).

CONCLUSIONS

Growing competition between sectors and states, as well as increasing signs of climate change, makes water resources

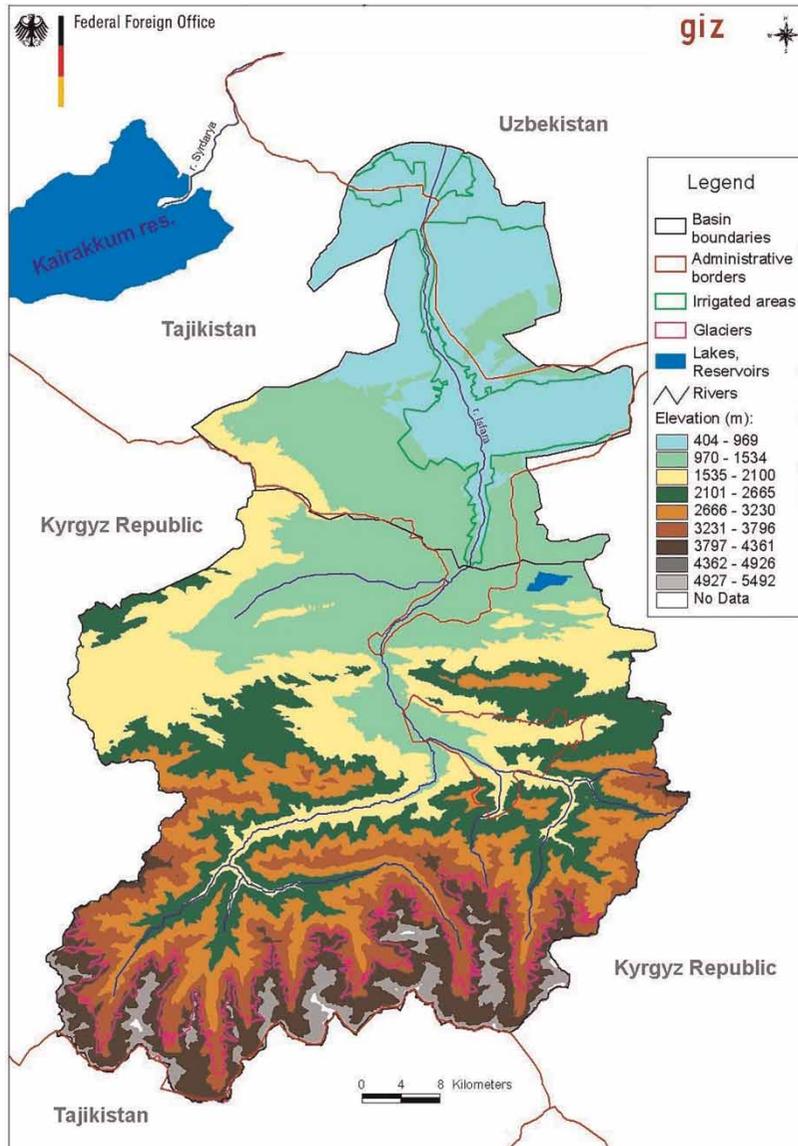


Figure 7 | Digital elevation model of transboundary Isfara river basin between Kyrgyzstan and Tajikistan.

management a challenge. In fact, this situation is more profound in transboundary river basins, where inter-sectoral competition is coupled with interstate aspects. About 250 river basins around the world are shared by two or more countries where issues of water resources have not yet been a reason for major conflicts (Wolf *et al.* 2003). However, growing demand for water and climate change impacts soon could mean that water becomes a source for instability.

Access to clean water for drinking, irrigation water for food security, and use of water for energy generation are

major areas of potential problems related to water resources management (IWMI 2011). Climate change will affect the formation, distribution and use of water resources. The quantity and quality of the water resources may decline from current levels in many parts of the world (IPCC 2007; GWP & INBO 2012).

The water consumption patterns will probably increase in most parts of the river basins, especially in transboundary ones due to an increase in air temperatures (IPCC 2007). Weak water management institutions, and the absence of long-term

basin plans on water management might worsen the situation further in developing countries (GWP 2011). Development of the data management tools and their application will help to reduce such risks and potential water-conflicts.

Data management for IWRM activities in selected sites shows that there is acknowledgement of the need to use modern information technologies in the decision-making process and the daily operation of national water management organizations for sustainable and efficient water management. In the future, widespread use of ICTs tools and approaches will help to enhance more transparent water management decision-making, increasing the public access to the water related data and information.

More transparent and publicly available data also makes cooperation of different sectors and countries dependent from the same water source much easier than it is at present. Successful implementation of the data management interventions in the water sector very much depend on existence of appropriate coordination institutions being in place for water management. Absence of such institutions is limiting the data and information sharing both within and between different sectors.

ACKNOWLEDGEMENTS

The views and information presented in this paper are of the authors, and not those of other individuals or organizations. The authors would like to thank Transboundary Water Management in Central Asia Programme, especially Dr V. Frobarth, Prof. Dr F. Schrader and the team, International Water Management Institute, Regional Office in Tashkent, Uzbekistan, A. Platonov, and Scientific Information Center of Interstate Commission for Water Coordination, D. Sorokin and the team. The authors are grateful to three anonymous reviewers of an earlier draft of this paper for constructive comments that helped us to improve the paper.

REFERENCES

- Abbott, M. B. & Jonoski, A. 2001 The democratisation of decision-making processes in the water sector II. *J. Hydroinform.* **3** (1), 35–48.
- Abdullaev, I. 2011 Can Better Governance along Solve Water Management Related Problems? 1st World Sustainability Forum. <http://www.sciforum.net/presentation/557> (accessed 21 November 2011).
- Abdullaev, I. & Atabaeva, S. 2012 Water sector in Central Asia: slow transformation and potential for cooperation. *Int. J. Sustain. Soc.* **4** (1/2), 103–112.
- Abdullaev, I. & Mollinga, P. P. 2010 The socio-technical aspects of water management: Emerging trends at grass roots level in Uzbekistan. *Water* **2** (1), 85–100.
- Abdullaev, I. & Rakhmatullaev, S. 2011 Supporting transboundary cooperation through data management for IWRM: a case from Central Asia. A paper presented at International Water Association 1st Central Asian Regional Young Water Professionals Conference, September 22–24, 2011, Almaty, Kazakhstan, pp. 128–139.
- Abdullaev, I. & Rakhmatullaev, S. 2012 Information systems in water sector of Central Asia: challenges and perspectives. In A paper presented at USCID Conference on Irrigated Agriculture responds to water use challenges – strategies for success, April 3–6, 2012, Austin, Texas, USA, pp. 41–54.
- Abdullaev, I., Kazbekov, J., Manthritilake, H. & Jumaboev, K. 2009 Participatory water management at the main canal: a case from South Ferghana Canal in Uzbekistan. *Agric. Water Manage.* **96** (2), 317–329.
- Abdullaev, I., Rakhmatullaev, S., Platonov, A. & Sorokin, D. 2012 Improving water governance in Central Asia through application of data management tools. *Int. J. Environ. Stud.* **69** (1), 151–168.
- Abdullaev, I., Manthritilake, H. & Kazbekov, J. 2010 Water and geopolitics in Central Asia. In: *Water, Environmental Security and Sustainable Rural Development: Conflict and Cooperation in Central Eurasia* (M. Arsel & M. Spoor, eds), Routledge, New York, pp. 125–143.
- Aminova, M. & Abdullaev, I. 2009 Water management in a state-centered environment: water governance analysis of Uzbekistan. *Sustainability* **1** (4), 1240–1265.
- Bastiaanssen, W. G. M. 1998 *Remote Sensing in Water Resources Management: The State of the Art*. International Water Management Institute, Colombo, Sri Lanka.
- Biswas, A. K. 2008 Integrated water resources management: Is it working? *Int. J. Water Resour. Dev.* **24** (1), 5–22.
- Biswas, A. K. & Tortajada, C. 2010 Future water governance: problems and perspectives. *Int. J. Water Resour. Dev.* **26** (2), 129–139.
- Cawater-Info Web portal 2011 <http://www.cawater-info.net/bd/index.htm> (accessed 13 August 2011).
- Cesur, D. 2007 GIS as an information technology framework for water modeling. *J. Hydroinform.* **9** (2), 123–134.
- Chemin, Y., Platonov, A., Ul-Hassan, M. & Abdullaev, I. 2003 Using remote sensing data for water depletion assessment at administrative and irrigation-system levels: case study of the Ferghana Province of Uzbekistan. *Agric. Water Manage.* **64** (3), 183–196.
- Chemin, Y., Platonov, A., Abdullaev, I. & Ul-Hassan, M. 2005 Supplementing farm-level water productivity assessment

- by remote sensing in transition economies. *Water Int.* **30** (4), 1–10.
- Choi, J. Y., Engel, A. B. & Farnsworth, L. R. 2005 Web-based GIS and spatial decision support system for watershed management. *J. Hydroinform.* **7** (3), 165–174.
- Conrad, C., Dech, S. W., Hafeez, M., Lamers, J., Martius, C. & Strunz, G. 2007 Mapping and assessing water use in a Central Asian irrigation system by utilizing MODIS remote sensing products. *Irrig. Drain. Syst.* **21** (3–4), 197–218.
- Conrad, C., Fritsch, S., Zeidler, J., Rucker, G. & Dech, S. 2010 Per-field irrigated crop classification in arid Central Asia using SPOT and ASTER data. *Remote Sens.* **2**, 1035–1056.
- Curry, M. R. 1999 Rethinking rights and responsibilities in GIS: beyond the power of imagery. *Cartogr. Geogr. Inf. Syst.* **22**, 58–69.
- Dukhovny, V. A. 2007 Water and globalization: case study of Central Asia. *Irrig. Drain.* **56**, 489–507.
- Eludoyin, A. O., Akinbode, O. M. & Ediang, O. A. 2007 Challenges of river basin information system (RBIS) as a framework for the assessment and monitoring of surface water in Nigeria. In *A paper presented at the International Symposium on New Directions in Urban Water Management*, September 12–14, 2007, Paris.
- Fortes, P. S., Platonov, A. E. & Pereira, L. S. 2005 GISAREG – A GIS based irrigation scheduling simulation model to support improved water use. *Agric. Water Manage.* **77**, 159–179.
- Gaiser, T., Printz, A., Schwarz von Raumer, H. G., Gotzinger, J., Dukhovny, V. A., Barthel, R., Sorokin, A., Tuchin, A., Kiourtsidis, C., Ganoulis, I. & Stahr, K. 2008 Development of a regional model for integrated management of water resources at the basin scale. *Phys. Chem. Earth* **33**, 175–182.
- Garcia, L. 2008 Integrated water resources management – a ‘small’ step for conceptualists, a giant step for practitioners. *Int. J. Water Resour. Dev.* **24** (1), 23–36.
- Grossmann, T. 2005 Kooperation an Afrikas Internationalen Gewässern Die Bedeutung des Informationsaustauschs. Bonn DIE Discussion paper 9/2005.
- GWP & INBO 2009 A Handbook for Intergrated Water Resources Management in Basins. Report of the Global Water Partnership and the International Network of Basin Organizations. Elanders Publishers, Sweden.
- GWP & INBO 2012 The Handbook for Intergrated Water Resources Management in Transboundary Basins of Rivers, Lakes and Aquifers. Report of the Global Water Partnership and the International Network of Basin Organizations. Elanders Publishers, Sweden.
- GWP 2000 Integrated Water Resources Management. TAC Background paper No. 4, Global Water Partnership, Stockholm.
- GWP 2011 Social Equity and Integrated Water Resources Management. Background Paper No. 15 of the Global Water Partnership Technical Committee. Elanders Publishers, Sweden.
- Hoekstra, A. Y. 2011 The global dimension of water governance: why the river basin approach is no longer sufficient and why cooperative action at global level is needed. *Water* **3**, 21–46.
- IPCC 2007 *Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (M. P. Parry, O. F. Canziani, J. P. Palutikof, P. J. van der Linden & C. E. Hanson, eds). Cambridge University Press, Cambridge, UK and New York, USA.
- IWMI 2011 IWMI Annual Report 2010. International Water Management Institute, Colombo, Sri Lanka.
- Kariyeva, J. & van Leeuwen, J. D. W. 2011 Environmental drivers of NDVI-based vegetation phenology in Central Asia. *Remote Sens.* **3**, 203–246.
- Long, N. 2001 *Development Sociology. Actors Perspective*. Routledge, London and New York.
- McDonnell, A. R. 2008 Challenges for integrated water resources management: How do we provide the knowledge to support truly integrated thinking? *Int. J. Water Resour. Dev.* **24** (1), 131–143.
- Merem, E. C., Yerramilli, S., Twumasi, Y. A., Wesley, J. M., Robinson, B. & Richardson, C. 2011 The applications of GIS in the analysis of the impacts of human activities on South Texas watersheds. *Int. J. Environ. Res. Public Health* **8**, 2418–2446.
- Mergili, M. & Schneider, J. F. 2011 Regional-scale analysis of lake outburst hazards in the southwestern Pamir, Tajikistan, based on remote sensing and GIS. *Nat. Haz. Earth Syst. Sci.* **11**, 1447–1462.
- Michalski, W., Miller, R. & Stevens, B. 2001 *Governance in the 21st century: Power in the global knowledge economy and society. In: Governance in the 21st Century*. OECD Future Studies, Paris, pp. 7–26.
- Mollinga, P. 2008 Water, politics and development. Framing a political sociology of water resources management. *Water Alternat.* **1**, 7–23.
- Moody, R. & van Ast, J. A. 2012 Implementation of GIS-based applications in water governance. *Water Resour. Manage.* **26**, 517–529.
- MySQL Web-site <http://www.mysql.com> (accessed 10 October 2011).
- Ozdogan, M., Yang, Y., Allez, G. & Cervantes, C. 2010 Remote sensing of irrigated agriculture: opportunities and challenges. *Remote Sens.* **2**, 2274–2304.
- Pechstädt, J., Bartosch, A., Zander, F., Schmied, H. M. & Flügel, W. A. 2011 Development of a River Basin Information System for a Sustainable Development in the Upper Brahmaputra River Basin. <http://www.brahmatwinn.uni-jena.de/> (accessed 1 September 2011).
- Pereira-Cardenal, S. J., Riegels, N. D., Berry, P. A. M., Smith, R. G., Yakovlev, A., Siegfried, T. U. & Bauer-Gottwein, P. 2011 Real-time remote sensing driven river basin modeling using radar altimetry. *Hydrol. Earth Syst. Sci.* **15**, 241–254.
- PHP Web-site <http://www.php.net> (accessed 5 September 2011).
- Pickles, J. 1995 *Ground Truth: The Social Implications of Geographic Information Systems*. Guildford Press, New York.
- Pickles, J. 1999 Arguments, debates and dialogues: the GIS-social theory debate and the concern for alternatives. In: *Geographical Information Systems: Principles and Technical*

- Issues (P. A. Longley, M. F. Goodchild, D. J. Maguire & D. W. Rhind, eds). John Wiley, New York, pp. 49–60.
- Platonov, A., Thenkabail, S. P., Biradar, M. C., Cai, X., Gumma, M., Dheeravath, V., Cohen, Y., Alchanatis, V., Goldshlager, N., Ben-Dor, E., Vithanage, J., Manthirithilake, H., Kendjabaev, S. & Isaev, S. 2008 **Water productivity mapping (WPM) using Landsat ETM+ data for the irrigated croplands of the Syrdarya River basin in Central Asia.** *Sensors* **8**, 8156–8180.
- Puls, F. 2011 **WorldBiew-2: The benefits of the 8 Spectral Bands and local tasking.** In: *A paper presented at the Fifth Annual Central Asian GIS Conference (GISCA'11) Geoinformatics: Managing Environment, Resources and Risk*, May 19–20, 2011, Almaty, Kazakhstan.
- Raadgever, G. T., Mostert, E., Kranz, N., Interwies, E. & Timmerman, J. G. 2008 **Assessing management regimes in transboundary river basins: do they support adaptive management?** *Ecol. Soc.* **13** (1), 14.
- Rakhmatullaev, S., Marache, A., Huneau, F., Le Coustumer, P., Bakiev, M. & Motelica-Heino, M. 2010a **Geostatistical approach for the assessment of water reservoir capacity in arid regions: a case study of the Akdarya reservoir, Uzbekistan.** *Environ. Earth Sci.* **63** (3), 447–460.
- Rakhmatullaev, S., Huneau, F., Le Cousumer, P. & Motelica-Heino, M. 2010b **Sustainable irrigated agricultural production of countries in economic transition: challenges and opportunities (a case study of Uzbekistan, Central Asia).** In: *Agricultural Production* (F. C. Wager, ed.), Nova Science Publ., New York, USA, pp. 139–161.
- Sadoff, C., Greiber, T., Smith, M. & Bergkamp, G. 2008 **Share. Managing Water Across Boundaries.** Report of International Union for Conservation of Nature and Natural Resources. Gland, Switzerland.
- Schmeier, S. 2011 **Navigating cooperation beyond the absence of conflict: mapping determinants for the effectiveness of river basin organizations.** *Int. J. Sustainable Society* **4** (1/2), 11–27.
- Sokolov, V. 2006 **Experiences in IWRM in the Central Asia and Caucasus region.** *Water Int.* **31** (1), 59–70.
- Thenkabail, P. S., Hanjra, M. A., Dheeravath, V. & Gumma, M. 2010 **A holistic view of global croplands and their water use for ensuring global food security in the 21st century through advanced remote sensing and non-remote sensing approaches.** *Remote Sens.* **2**, 211–261.
- Tortajada, C. 2010 **Water governance: a research agenda.** *Water Resour. Dev.* **26** (2), 309–316.
- UNDESA 'e-Government Readiness Knowledge Base' 2011 **The United Nations Department of Economic and Social Affairs.** <http://www.unpan.org/egovkb> (accessed 20 October 2011).
- UNDP 2005 **Bringing Down Barriers: Regional Cooperation For Human Development And Human Security.** Central Asia Human Development Report of United Nations Development Programme. UNDP Regional Bureau for Europe and the Commonwealth of Independent States, Bratislava, Slovak Republic.
- UNDP 2008 **United Nations E-government Survey 2008: From E-government to Connected Governance.** Report of United Nations Development Programme, UN Publishing Section, New York, USA.
- UNEP 2005 **Global International Waters Assessment: GIWA Aral Sea Regional Assessment 24.** Report of United Nations Environmental Programme. University of Kalmar Publ, Kalmar, Sweden.
- van Griensven, A., Breuer, L., Di Luzio, M., Vandenberghe, V., Goethals, P., Meixner, T., Arnold, J. & Srinivasan, R. 2006 **Environmental and ecological hydroinformatics to support the implementation of the European Water Framework Directive for river basin management.** *J. Hydroinform.* **8** (4), 229–252.
- Wallace, R., Pathak, K., Fife, M., Jones, N. L., Holland, J. P., Stuart, D., Harris, J., Butler, C. & Richards, D. R. 2006 **Information infrastructure for integrated ecohydraulic and water resources modeling and assessment.** *J. Hydroinform.* **8** (4), 317–333.
- WB 2003 **Irrigation in Central Asia: Social, Economic and Environmental Considerations.** Report of the World Bank. <http://www.worldbank.org/eca/environment>, (accessed 23 May 2011).
- Wegerich, K., Kazbekov, J., Lautze, J., Platonov, A. & Yakubov, M. 2011 **From monocentric ideal to polycentric pragmatism in the Syr darya: searching for second best approaches.** *Int. J. Sustain. Soc.* **4** (1/2), 113–130.
- Wolf, A. T., Yofee, S. B. & Giordano, M. 2003 **International waters: Identifying basins as risk.** *Water Pol.* **5** (1), 29–60.
- Yakubov, M. & Ul Hassan, M. 2007 **Mainstreaming rural poor in water resources management: Preliminary lessons of a bottom-up WUA development approach in Central Asia.** *Irrig. Drain.* **56**, 261–276.
- Yalcin, R. & Mollinga, P. P. 2007 **Institutional Transformation in Uzbekistan's Agricultural and Water Resources Administration: The Creation of a New Bureaucracy.** Working Paper Series No. 22. Center for Development Research (ZEF) University of Bonn, Bonn, Germany.

First received 22 May 2012; accepted in revised form 20 April 2014. Available online 29 May 2014