C. CONRAD[1], S. SCHÖNBRODT-STITT[1], I. ABDULLAEV[3], D. DIMOV[1], M. IBRAKHIMOV[2], P. KNÖFEL[1], M. LEINICH[3], L. MORPER-BUSCH[1], G. SCHORCHT[4], G. SOLODKY[5], A. SOROKIN[5], D. SOROKIN[5], G. STULINA[5], R. TOSHPULATOV[5], K. UNGER-SHAYESTEH[6], S. ZAITOV[5], V. DUKHOVNY[5]

[1]Remote Sensing Unit, Institute of Geography, University of Wuerzburg, Wuerzburg,Germany
[2]Khorezm Rural Advisory Support Service (KRASS), Urgench, Khorezm, Uzbekistan
[3]The Regional Environmental Center for Central Asia (CAREC), Almaty, Kazakhstan
[4]green spin GmbH, Wuerzburg, Germany
[5]Scientific-Information Center of the Interstate Coordination Water Commission of Central Asia (SIC-ICWC),Tashkent, Uzbekistan
[6]Helmholtz Centre Potsdam, German Research Centre for Geosciences (GFZ),Germany

REMOTE SENSING AND GIS FOR SUPPORTING THE AGRICULTURAL USE OF LAND AND WATER RESOURCES IN THE ARAL SEA BASIN

Globally, the sustainable management of water resources is in the spotlight of academic and institutional, respectively governmental interest and activities. Against the background of climate change, drylands such as in the Aral Sea Basin (ASB) in Central Asia outline a focus area on the water usage for the purpose of irrigation towards food security and promotion of sustainable agriculture. Additionally, the fact of transboundary rivers, thus, water resources highly elicits a call for action to coordinate interstate water relations towards an efficient water usage. Here, the regional research network 'Central Asian Water' (CAWa) aims at developing a scientifically sound and reliable regional database for theimplementation of sustainable water management strategies in the ASB. The CAWa work packageIII 'Online Tool for the Monitoring of the Water Use Efficiency and the Agrarian Land Use' focuses on the generation ofsuch a database on land use and water usage in the ASB by means of state-of-the-art remote sensingtechniques. The application of this technology is promising in Central Asia due to favoring atmospherically (i.e., cloud-free) conditions. It enables for a regular derivation and monitoring of biophysical parameters on the state of land and water resources (i.e., land use, biomass, crop yield, evapotranspiration). The use of Geographical Information Systems (GIS) enables, among others, the derivation of supportive information on irrigated cropland area and its productivity for gaining abetter understanding of the land use intensity. These modern techniques can now contribute to andfurther develop a system of existing, effective and analytical land and water use related indicators forestimating the productivity of irrigated agriculture, for comparing irrigation systems, and for monitoring performance of irrigation systems over times. With the development of the web-based GIS tool WUEMoCA, the CAWa team is working on anautomated monitoring and visualization instrument that particularly addresses sustainable decisionmaking and program planning processes to ensure environmental and socio-economic stability in Central Asia and Afghanistan.

Introduction. In 2015, the UN declared in its World Water Development Report that never before the earth has been thirstier than now [1]. Without any substantial reforms on the consumption, management, and allocation of the water resources, water scarcity in all sectors will mainly endanger drinking water and food security. By the year 2030, the gap between water demand and natural groundwater recharge could increase to 40% [1]. Population growth, the increasing demand of irrigation water, urbanization, and climate change are assumed to even aggravate this situation [2,3].Water scarcity already constitutes the most urgent problem and most challenging issue of prospective politics in water management. According to the UN report, particularly dryland regions such as the Aral Sea Basin (ASB) in Central Asia will be affected [1]. The ASB gained prominence in the recent past with the desiccation of the formerly world's fourth largest lake, the Aral Sea, to 10% of its original surface by 2007 [4]. This environmental catastrophe [5,3] is largely considered to result from serious anthropogenic interferences into the vulnerable arid ecosystem by inappropriately performed land development programs and excessive use of irrigation water during the Soviet Union [6,7]. The ASB constitutes one of the largest irrigation cropping areas in the world [7]. Latest results from a studyincorporating moderate and high resolution RS-data (MODIS and Landsat) and covering an observation period of 13 years indicate a total area of 8.4 Mio ha of total irrigated cropland, thus confirming further according results in the ASB [7].Irrigation water amounts to more than 90% of the total intake from all water sources [8]. However, the reduced manageability at lowest (on-farm) level and transboundary problem [9] in combination with the above challenges have been further stated as immanent recent factors threatening water as the most precious resource and towards a source of conflict [10]. Land and water management in the ASB is a multisector topic highly requesting an integrated holistic approach on the sustainable water and land management and addressing different institutional levels. Proclaimed in the Sustainable Development Goals (SDGs), it is of key importance to look at the water cycle in its entirety and the role of all uses and users [11]. Particularly, international cooperation and stakeholder participation present important aspects in the mutual goal of sustainable water resource management [11].

During the international decade for action ‘Water for Life’ (2005-2015), the German Federal Foreign Office has launched the German water initiative for Central Asia (so called ‘Berlin Process’) in April 2008 within the framework of the European Union strategy ‘Central Asia’. As the scientific component of this initiative, the regional research network «Central Asian Water» (CAWa) was designed to support scientific cooperation and communication between Central Asian countries and Germany in the sector of water resource management. Important activities of CAWa (2009-2017) cover the development of a scientifically sound and reliable regional database for the implementation of sustainable water management strategies in the ASB. In its third phase (2015-2017), CAWa holistically aims at the consolidation, capacity building, and transfer as well as dissemination of data and scientific resultsin the context of limited water resources and towards the development of sustainable land and water management options.Since the agricultural sector presents the largest consumer of water in the ASB, a distinct focus of CAWa lies on the data-driven analysis of the role of irrigation water in an integrated manner [7]. Key topic within the CAWa work package III ‘Online Tool for the Monitoring of the Water Use Efficiency and the Agrarian Land Use’ is the efficient water use for irrigation purposes implying a bundle of issues to be addresses first. These *inter alia* include thecomprehensive understanding of the quality and quantity of land use and cropping intensities and their spatio-temporal variability as well as determining factors (e.g., evapotranspiration) for estimating the productivity of irrigated cropland (i.e., yield estimation).

Monitoring is considered to offer great potential in the operational and systematic recording, observation, and early estimation of all irrigation related questions. It denotes for the periodic or continuous collection of data by measuring the relevant parameters in a broad range of environmental processes using consistent, respectively, standardized methods.Remote sensing (RS) can contribute some of the keyindicators for monitoring in land and water management by serving as fast supplier of high-quality data of often high spatial and temporal resolutions and covering large areas, and by enabling change detection through repeated spatially-explicit earth observations [12].Thus, RS data allow for a continuous monitoring of parameters to achieve the data-driven, indicator-based stateof water use efficiency within the framework of CAWa. Required indicators derived from gathered parameters and feeding the monitoring system ideally present simple, developed and validated measures and serveas practical numerical values on the complex state of water use efficiency in the ASB [13]. Anumber of effective indicators can be consulted to provide scientific insight into the state of the environment and the anthropogenic impact on it [13]. Relevant indicators allow to reveal the trigger mechanisms and responses steering that system, however, provided that they fulfill a list of standard requirements, which basically stress the relevance and reliability of information, the easy interpretation and comprehensibility of information indicated as well as their response to changes in the system and their projection to different geographic scales [12,13,14,15].

Problem definition. In context of the development and operationality of the water use efficiency monitoring in the highly complex human-environment system of the ASB [16,17],the overall aims of CAWa work package III are basically: (i) generation of a database using RS techniques, (ii) derivation of supportive information on irrigated cropland using GIS, and (iii) development of a set of land-, crop- and water related indicators. Finally, theirimplementation will serve as key prerequisites for the development of an automated monitoring and visualization instrument to provide a platform linking scientific results and decision making in sustainable land and water management.

With this contribution to the international scientific-practical conference 'Water Resources of Central Asia and their Use', the authors would aim at presentinga brief overview on the current state of joint research and development of that monitoring tool.

Research methodology.

Study area. Study activities spatially focus on the irrigated cropland extent (iCE) in the landlocked ASB (Figure 1). In its southeast, it is framed by the high mountain ranges of Pamir, Alai, Tian Shan, and Hindukush where runoff contributing to the major water supply in the ASB [7] is generated from precipitation and largely depends on the rhythm of glaciation [18]. The central inner ASB is characterized by the plains of the deserts of Kyzyl Kum and Kara Kum. Climate is continental, arid to semi-arid. Resulting from the topographic gradient with altitudes ranging from 0 to 7,500 m a.s.l. [19] average annual precipitation (mainly in winter and spring) ranges from80 to 200 mm in the lowlands and valleys (e.g., Fergana), from 300 to 400 mm at the foothills, and from 600 to 800 mm in the mountain ranges [10]. The ASB typically shows hot and dry summer seasons and cold humid winters [20,21,22]. Due to high annual evapotranspiration rates up to approximately 1,200 mm in Turkmenistan [23], the annual water balance is negative, thus water is a limited resource. Cropping heavily depends on irrigation water supplied by the two main river systems of the Amu Darya and Syr Darya as well as the artificial Kara Kum Canal [7].

Main crops are wheat, rice, maize, and barley totally amounting to an area of almost 49% of the entire iCE, as well as cotton with an area percentage of approximately 23% [10]. Smallest area proportion (approximately 16%) is cropped with fodder and permanent crops [7]. In a RS-based analysis of cropping intensity in the ASB,Conrad et al. distinguished eight large-scale irrigation zones (Figure 1) with a total irrigated area estimated to 8.4 Mio ha [7]. These are: (i) Fergana valley (Uzbekistan and Kyrgyzstan, (ii) Tashkent and Syr Darya (Uzbekistan and Kazakhstan), (iii) Chardara, Aris, and (iv) Kyzyl Orda (all Kazahkstan), (v) Upper Amu Darya (Uzbekistan, Tajikistan, and Afghanistan), (vi) Zerafshan and Amu Darya (Uzbekistan and Turkmenistan), (vii) Kara Kum Canal (Turkmenistan), and (viii) Amu Darya Delta (Uzbekistan and Turkmenistan). The long-term (2000-2012) average cropping intensity referring to the number of harvest for a cropland area per year [24] has recently been reported to vary between highest 1.09 in Fergana to lowest 0.83 in the downstream irrigation zones alongside the Amu Darya River [7].

Data sources and Geodatabase. Data for monitoring originate from 250m MODIS (Moderate Resolution Imaging Spectroradiometer) MOD09Q1 data products that are automatically obtained through the online Data Pool at the NASA Land Processes Distributed Active Archive Center (LP DAAC), USGS/Earth Resources Observation and Science (EROS) Center, Sioux Falls, South Dakota (https://lpdaac.usgs.gov/data_access). Data is provided as an 8-day aggregate, ensuring cloud-free images with a high temporal resolution. The Normalized Difference Vegetation Index (NDVI) is then calculated for each scene from the provided red and near-infrared spectral bands of the MODIS product. Even though the pixel size of 250m does not allow for the detection of single fields, the MODIS data sets were selected because WUEMoCA is designed as a regional tool for monitoring and MODIS is currently the only satellite system in space that covers extensive areas such as the ASB with the required temporal resolution for the generation of consistent time series from 2000 until today.Vector data on the administrative and water distribution levels in the ASB are provided by the Scientific-Information Center of the Interstate Coordination Water Commission of the Central Asia (SIC ICWC). Actual data on the land use distribution, the crop types as well as yield (i.e., biomass) to be harmonized and use as training and validation data originate from comprehensive field surveys by the Central Asian partners.

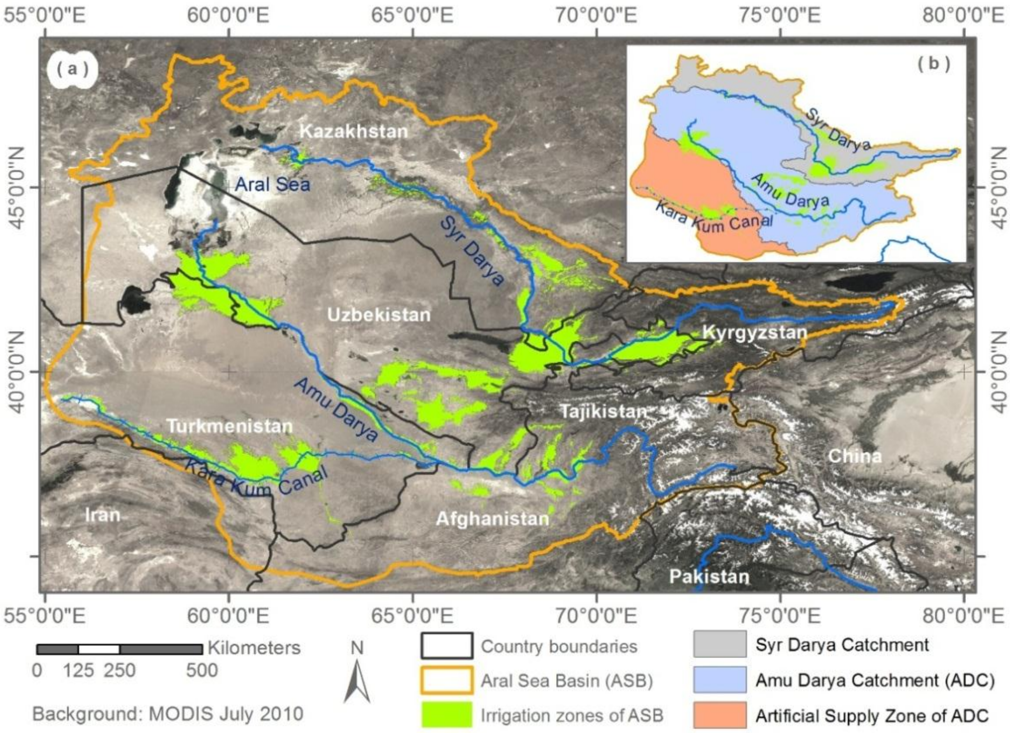

Figure 1 - (a) Geographic location of the Aral Sea Basin in Central Asia and covering countries as well the location of the irrigation zones alongside the courses of the rivers Amu Darya and Syr Darya, and the Kara Kum Canal. (b) Overview on the location of the largest river catchments of Amu Darya and Syr Darya in landlocked Central Asia and the artificial water supply zone receiving water from the Kara Kum Canal. Source: Conrad et al. (2016).

Development and design of the monitoring and visualization tool. The monitoring and visualization tool WUEMoCA (Water Use Efficiency Monitor in Central Asia) is designed as a coherent and fully automated processing chain to visualize relevant indicators at different levels of aggregation within an interactive, freely accessible web-based platform (i.e., webGIS). The automated classification and processing of MODIS images is therefore the basis for data provision. Land use and yield data will be derived annually for the observation period from 2000 to 2015. An additional near-real time mode is considered to provide bi-weekly biomass estimations during the operational status of the system. The system architecture of WUEMoCA is sub-partitioned into five main modules: (i) land use classification, (ii) yield estimation, (iii) geodatabase processing, (iv) map server and client application, and (v) user database and on-the-fly aggregation. Generally, WUEMoCA starts with the continuous automated download of new MODIS data (8day-step) independently from manual control, and their automated storage on a local folder of the WUEMoCA server that subsequently triggers the automatized process of land use classification and yield estimation, and providesthe results to the PostGIS geodatabase. PostGIS acts as a spatial database for vector and raster data and is used as a storage from where a MapServer converts the data to web-based services and transfers them to a web client (i.e., web browser). Within the database, the tables of vector geometries such as administrative levels (e.g., oblast/province and rayon/district and water distribution levels (e.g., in Uzbekistan, Basin Irrigation System Authority (BISA), Irrigation System Authority (ISA), water use associations (WUAs), and channel command areas) are populated through spatially aggregating the raster-based results. The resulting vector data tables present the basis for the visualization in the web mapping application. The specific technical requirements for MODIS image processing and data processing as well as for the client application, the mapping standards, and the software applied for developing WUEMoCA are given in Table 1.

Table 1 – Technical requirements and software applied for developing WUEMoCA.

Purpose	**Software, Standards**
Satellite image processing	R & JAVA programming libraries
Database with spatial extension	PostgreSQL, incl. PostGIS
Database processing	Python programming libraries
Web mapping application (client)	HTML, CSS, JavaScript APIs (OpenLayers, ExtJS, GeoExt), JSP
Data exchange formats	WMS, WMTS(both Open Geospatial Consortium Standards)
Map server	GeoServer
Web server	Apache Tomcat
Operational system	Windows server

Indicator system on land and water use. Indicators calculated and visualized in WUEMoCA generally aim at estimating the performance of the irrigated cropland within the focused boundaries of irrigations system (e.g., WUA, channel command area) in the irrigation planning zones in the ASB (Figure 1). They further aim at comparing the irrigation systems such as by indicating the productivity in the different planning zones of riparian countries (e.g., Fergana and Khorezm). By incorporating multi-temporal RS data (2000-2015), derived indicators might also spot at the performance of the irrigation systems over time (multi-annually and annually). Indicators recently implemented can basically be grouped into land related and crop related indicators (Table 2) since they are considered to serve as essential prerequisites in further developing an indicator systems stressing the water use efficiency of the irrigated cropland.

Research results. WUEMoCA is anopen-source coherent, fully automated, online RS and GIS-based tool for the regional monitoring of irrigated cropland in the Aral Sea Basin. It allows for interactivelyexploring, filtering and analyzing the indciators implemented at different aggregation levels.Scientific information is provided to the userin Russian and English languages via commonly applied web mapping standards and routines (client-server-data system). The open-source software GeoServer therefore acts as map server that links the client application and spatial database (PostgreSQL/PostGIS). The map server creates WMS (web map service) and WMTS (web map tile service) map layers from geospatial tables that are are synchronized and compliant to the standards by Open Geospatial Consortium (OGC). User-specific request from the client, which is written in HTML, CSS, and JavaScript (OpenLayers), are sent to and processed by GeoServer (map server reading the geodatabase), which then returns the desired responses to the client. WUEMoCA is a three-component WebGIS (database, map server, and client application; Figure 2), which surface is designed to be freely available via internet with every current web browser.It contains detailed annual maps of land use and crop yield based on openly accessibleMODIS data for the observation period from 2000 to 2015. It allows to calculate and visualize relevant annual and multi-annual land and crop related indicators at the administrative level and the water distribution level as well as aggregated in a raster with a cell size of currently 5 km * 5 km. Important features of the WUEMoCA graphical user web-interface are presented in Figure 3.

Table 2 – Land and crop related indicators (alphabetical order) currently implemented in WUEMoCA. For the annual indicators, the calculation is based on one single year within the total observation period (2000-2015). For the multi-annual indicators, the average is taken from 2000 to 2015. State: July 2016.

Name of indicator	**Time scale**	**Notes**
Land related indicators		
Gross irrigated land area	annual	Net irrigated land area (ha) + the related area under canals, structures, roads, and buildings
Net irrigated land area	annual	Potentially usable irrigation area (ha)
Land use coefficient	annual	Quotient of the net irrigated land area and gross irrigated land area
Land use intensity	annual	Percentage (%) of area showing double season cropping
Net irrigated land use	annual	Actual use of net irrigated land area (%), double season is counted twice
Unused irrigated land	annual	Percentage (%) of net area classified as fallow land
Fallow land frequency	multi-annual	Number of years with fallow land
Crop related indicators		
Actual yield	annual	Yield (t ha^{-1}) of main crop types*
Actual farm gross output	annual	Farm output (tons) for main crop types**
Major land use	multi-annual	Predominating crop type (cotton, wheat, rice, fallow, orchard/vineyard, urban garden, other crop)
Crop rotation	multi-annual	Number of crop types
Irrigated crop acreage	annual	Irrigated area (ha) cultivated with different crops and total irrigated crop acreage for all crops
Irrigated land use per crop	annual	Percentage (%) of irrigated land cultivated with different crops (cotton, wheat, rice, orchard/vineyard, other crop, urban garden)
State order land use	annual	Percentage (%) of area cultivated with cotton and wheat

*currently available for cotton and wheat, **currently available for wheat

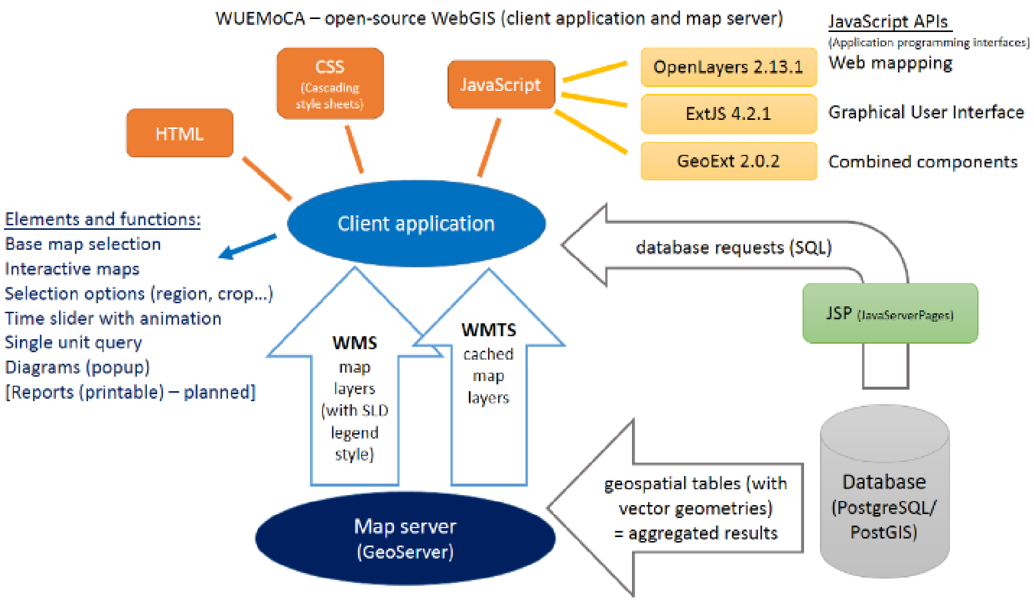

Figure 2 – WebGIS - Interaction between client application, map server, and database.

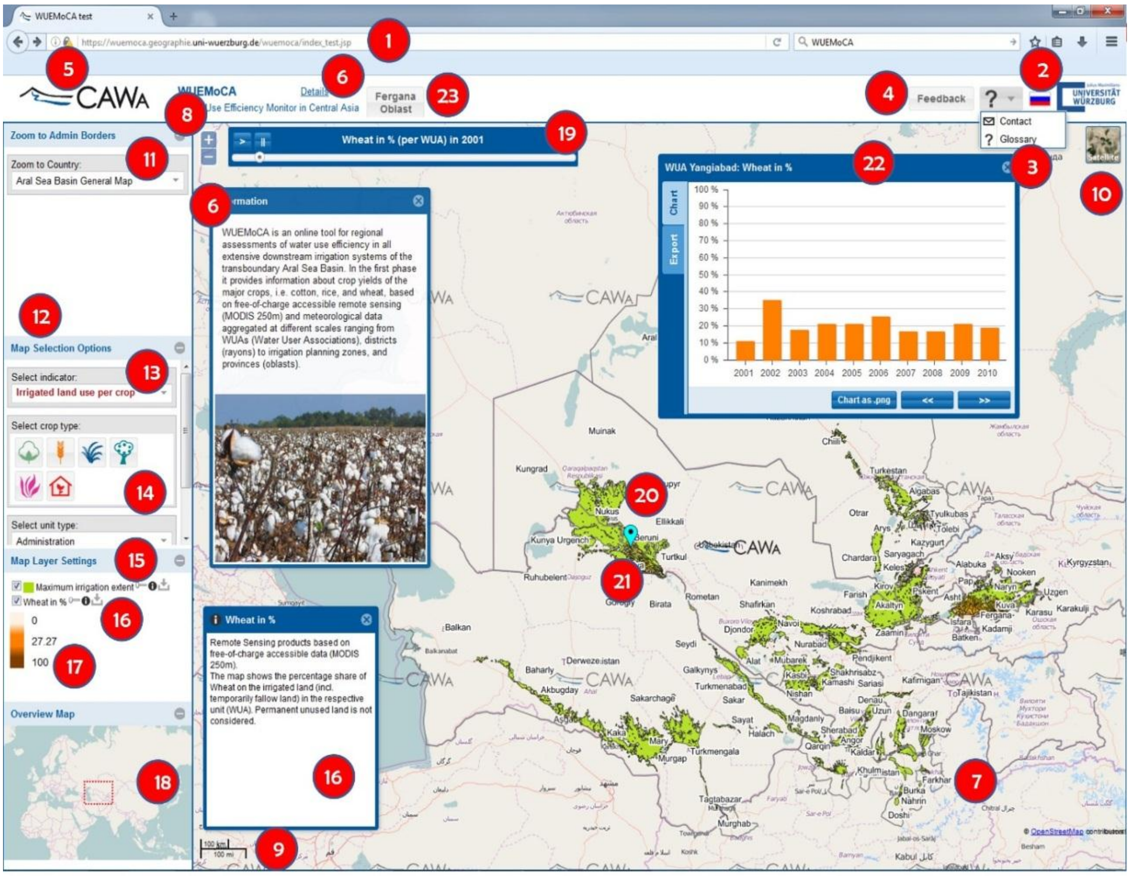

Figure 3 – WUEMoCA features at a glance are: (1) Website URL, (2) language (Rus, Eng), (3) glossary and disclaimer, (4) user feedback template, (5) link to CAWa homepage, (6) WUEMoCA information, (7) Web-interface window, (8) Zoom button, (9) Scale bar, (10) Satellite map, (11)Country Selection, (12) Map selection (e.g., administrative level, water distribution level), (13) Indicator selection, (14) Crop type selection, (15) Unit type selection, (16) Map layer settings and information, (17) Legend, (18) Overview map, (19) Time slider (2000-2015), (20) Single unit query, (21) Tooltip, and (22) Diagrams/export option. Screenshot of WUEMoCA test version, June 2016.

Currently, 14 land and crop related indicators are implemented into WUEMoCA (Table 2).

Figure 4 exemplarily shows preliminary, visualized results of the requested annual indicator ‘yield’ in Kashkadarya Province (approximately 28,500 km²) in southern Uzbekistan (divided into two planning zones (PZ): Karshi PZ and Kashkadarya PZ, [25] in the interactive web-interface WUEMoCA. The resulting yield from the MODIS-based land use classification is aggregated to a grid of a cell size of 5 km * 5 km clearly spotting at pixels of averagely low (yellow color) yields to averagely medium (orange color) and averagely high (green color) yields of the crops wheat and cotton.

Discussion. Since WUEMoCA is yet in the process of developing, results need to be considered as preliminary. However, first results as exemplarily shown in Figure 4 are assumed to approximate the RS-based land use and crop information in a valuable manner since they are in close agreement with scientific results from this region [7]. Figure 5 indicates a similar production pattern in the Kashkadarya Province with wheat as typical winter crop spatially concentrating in the southern and south-eastern irrigation area in the mountain foothills and cotton as typical summer crop mainly concentrating in the central irrigation area in the Karshi steppe (in 2005). WUEMoCA (Figure 4) - in contrast to the scientific output (Figure 5) - is designed to give overview information rather than a zoom to every single field. However, at both scales, the 250m pixel level and the WUEMoCA grid of

5km * 5km, particularly for cotton, but also for wheat (which is indicated in Figure 5 by a high amount of double cropping in 2005), both figures show an area increase between 2001 and 2005. This is considered to mainly result from the fact that in the Amu Darya catchment,the years 2000 and 2001 were identified as drought years [26]and 2005 as 'water-rich' year as visible in the CAREWIB database [27].

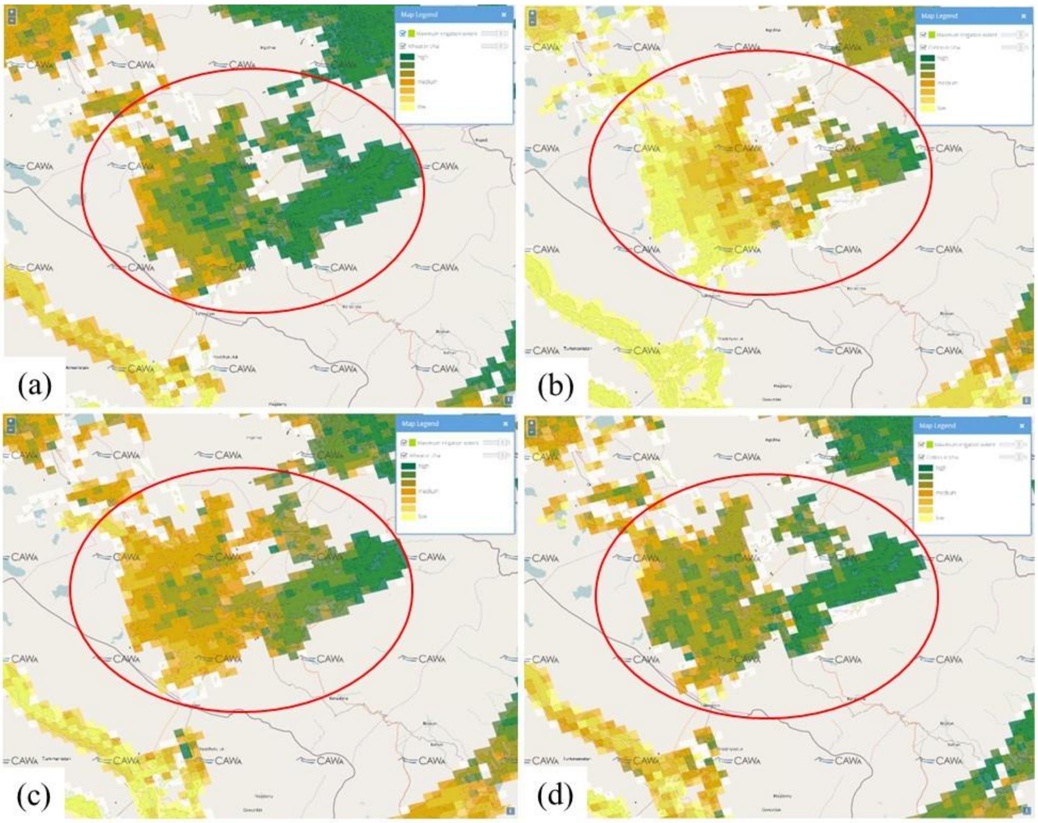

Figure 4 -Visualization of irrigated cropland use in WUEMoCA;output of the query on the indicator 'yield' use' in Kashkadarya Province (red framed) as exemplarily shown for (a) wheat in 2001 and (b) cotton in 2005 as well as (c) wheat in 2001 and (d) cotton in 2005. Results are aggregated to raster cell sizes of 5 km * 5 km. State: August 2016.

As a next step in developing the monitoring tool, validation of results will be conducted using field data, annual reports, and official statistics for Central Asia as this is mandatory to meet the need of reliability. Moreover, the tool itself will be further developed towards becoming increasingly user-specific. For instance, during the process of development and specification of user demands it turned out that the acquisition and/or provision of reliable aggregation geometries (e.g., administrative and water distribution levels) is challenging for WUEMoCA. Indicators aggregated directly to water supply zones that are assigned to a certain water source (e.g., channel command areas) are of particluar interest since they enable for directly evaluatingresult of water management decision, e.g., to assess the amount of water supplied via the different sources to the command area. Future developments will therefore also focus on theimproved applicability by providing a user polygon tool. This will allow for the interactive input of defined focus areas to get demand-specific results of all available post-processings (e.g., share of crop types, yield estimation). To avoid manipulations of the common database and to meet the necessity of plausibility checks, a client side user database will be developed, too.

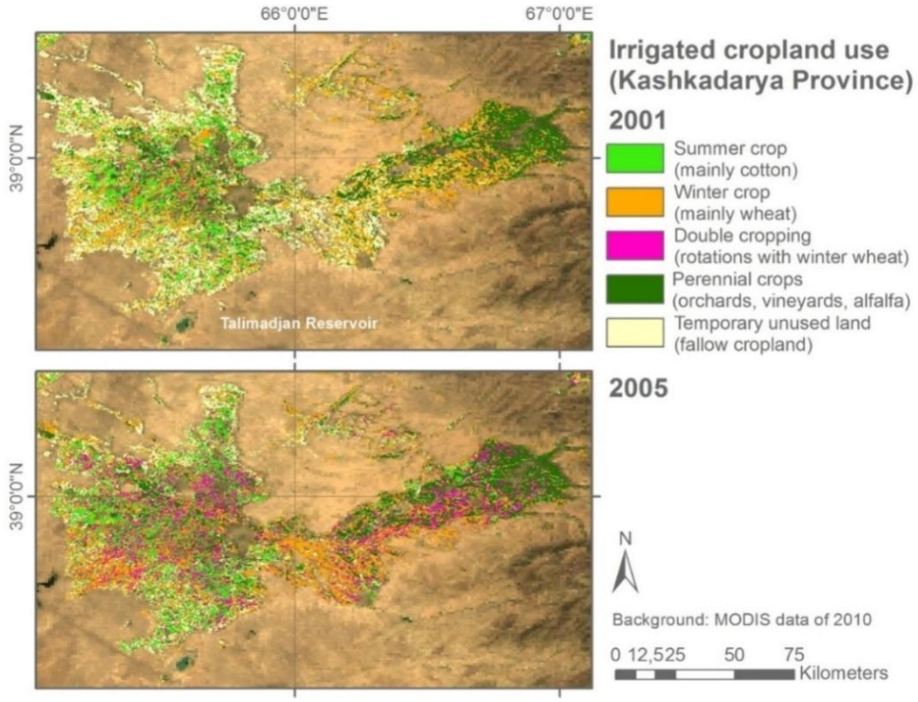

Figure 5 - Production pattern in 2001 (above) and 2005 (below) in the Kashkadarya Province in southern Uzbekistan. Results shown are based on results given by Conrad et al. (2016).

Furthermore, the system of indicators will be extented towards the integration of water-related indicators providing detailed information on the water supply for irrigation purpose and crop-specific water consumption, e.g. evapotranspiration [28]. Based on the concept of water accounting[29], the future proposed system of indicators is then considered to describe quantitativelyhow efficient the supplied water was used for crop production.Current activities focus on the challenging level of uncertainties resulting from the geometrical properties of the MODIS pixels by introducing a multi-level appproach on the calculation of gross and net areas of indicators and incorporating high-resolution Landsat data into the process of derivation of aggregation levels. The authors are aware that WUEMoCA is not ready yet. Moreover, it is clear that it may not supply every potential user with the desired data, for instance because it is not able to monitor every single field. However, the current state of WUEMoCA is promising in context of providing critical indicators to get an improved understanding of the land use and its intensity as well as the productivity of irrigated cropland for future comparison of irrigation systems, at least at regional scale.

Conclusion. WUEMoCA is an online, openly accessible GIS-based tool for the regional monitoring of irrigated cropland in the Aral Sea Basin. With the designed system of indicators, it aims at providing scientific results towards a broad user-community in Central Asia. The methods will contribute to the current data base and indicator systems at the regional scale and are foreseen to be implemented in modeling future perspectives, e.g., through the ASBmm model of SIC ICWC (http://sic.icwc-aral.uz/asbmm_e.htm). Potential future applications are considered to include assessments of marginal lands with low productivity, the intensity of land use, the early estimation of harvest shortfalls, and the assessment of water use efficiencies. WUEMoCA is concluded to lay the foundation for transferring scientific results to the regional applicants, not only in water management institutions. With the introduction of the new technologies this is expected also to attract the young generation and universities, which can be seen as important step towards long-term maintenance and regional spread of the potentials of RS and geoanalytical methods in context of in water management. Altogether, WUEMoCA might become a useful tool in support of planning in national and transboundary water-management organizations for refining principles in the land and water managements against the background of water scarcity in the vulnerable Aral Sea Basin.

Acknowledgements. This study was conducted within the framework of the work package III in the third phase of the regional research network «Central Asian Waters» (CAWa, www.cawa-project.net). The authors gratefully acknowledge funding from the German Federal Foreign Office (grant No. AA7090002) for the research of the interdisciplinary consortium of international and regional institutions.

REFERENCES

[1] WWAP (United Nations World Water Assessment Programme). 2015. The United Nations World Water Development Report 2015: Water for a Sustainable World. Paris, UNESCO, pp. 139, accessed at http://unesdoc.unesco.org (0718-2016).

[2] Lioubimtseva E., Henebry G.M., 2009. Climate and environmental change in arid Central Asia: Impacts, vulnerability, and adaptations. J. Arid Environ, 73, 963-977.

[3] Micklin P. (ed.), 2016. The future Aral Sea: hope and despair. Environ Earth Sci 75, 844. doi:10.1007/s12665-016-5614-5.

[4] Micklin P.P., Nikolay V.A., 2008.Reclaiming the Aral Sea. Scientific American 298, 64-71.

[5] Létolle R., Mainguet M., 1996.Der Aralsee. Eine ökologische Katastrophe. Springer Verlag Berlin. [in German]

[6] Micklin P.P., 1988. Dessication of the Aral Sea: a water management disaster in the Soviet Union. Science 241, 1170-1176.

[7] Conrad C., Schönbrodt-Stitt S., Löw F., Sorokin D., Paeth H., 2016.Cropping intensity in the Aral Sea Basin and its dependency from the runoff formation 2000-2012. Remote Sensing 8, 630, doi:10.3390/rs8080630

[8] EC IFAS. Water resources of the Aral Sea Basin. Accessed at http://ec-ifas.waterunites-ca.org(07-18-2016)

[9] Dukhovny V.A., 2010. Current problems in irrigated agriculture in Central Asia and future solutions. CAWa Symposium, November 24-26, 2010, Tashkent, Uzbekistan, 2010, presentation.Accessed at http://cawa-project.net (07-19-2016)

[10] Food and Agriculture Organization (FAO). Irrigation in Central Asia in Figures -AQUASTAT Survey - 2012; FAO: Rome, Italy, 2012.

[11] United Nations, 2015. Transforming our world: The 2030 agenda for sustainable development. A/RES/70/1, pp. 41.Accessed at https://sustainabledevelopment.un.org (0713-2016)

[12] Coops N.C., Bater C.W., 2009. Remote sensing opportunities for monitoring indicators of forest sustainability. FREP Report #21, Forest and Range Evaluation Program. Department of Forest Resources Management, University of British Columbia, Vancouver, pp. 53.Accessed at https://www.for.gov.bc.ca (07-21-2016)

[13] European Environmental Agency, 2016: Environmental terminology and discovery service (ETDS). Accessed athttp://glossary.eea.europa.eu (05-03-2016)

[14] The Encyclopedia of Earth, 2008. Environmental indicators. Accessed at http://www.eoearth.org (2016-05-03)

[15] Leadership Council of the Sustainable Development Solutions Network 2015. Indicators and a monitoring framework for the Sustainable Development Goals - Launching a data revolution for the SDGs, Revised working draft (V7), Global Initiative for the United Nations, pp. 215.Accessed at http://unsdsn.org (07-15-2016)

[16] Giese E., Bahro G., Betke D., 2008. Umweltzerstörungen in Trockengebieten Zentralasiens (West- und Ost-Turkestans): Ursachen, Auswirkungen, Maßnahmen. Erdkundliches Wissen 125, Franz Steiner Verlag Stuttgart, pp. 189. [in German]

[17] Bos M.G., Burten M.A., Molden D.J., 2005.Irrigation and drainage performance assessment - practical guidelines. CABI Publishing, CAB International, Oxfordshire, UK, pp. 166.

[18] Lioubimtseva E., 2015. A multi-scale assessment of human vulnerability to climate change in the Aral Sea Basin. Environmental Earth Sciences 73, 719-729.

[19] 19.FAO. 2016. AQUASTAT website. Food and Agriculture Organization of the United Nations (FAO). Accessed at http://www.fao.org/nr/water/aquastat/ (07-14-2016)

[20] Conrad, C., Schorcht, G., Tischbein, B., Davletov, S., Sultonov, M., Lamers, J.P., 2012. Agro-meteorological trends of recent climate development in Khorezm and implications for crop production. In: Cotton, Water, Salts and Soums. Springer, Dordrecht, Heidelberg, London, UK, pp. 25-36.

[21] Kirilenko A., Dronin N., 2011. Climate change and adaptations of agriculture in the countries of the Former Soviet Union. In: Yadav SS, Redden B, Hatfield JL et al (eds.) Crop adaptation to changing climates. Wiley-Blackwell, Hoboken, NJ, pp 84-106.

[22] Murray-Rust H., Abdullaev I., ul Hassan M., Horinkova V., 2003. Water productivity in the Syr-Darya river basin. Research Report 67. Colombo, Sri Lanka: International Water Management Institute. pp. 86.Accessed at http://www.iwmi.cgiar.org (07-25-2016)

[23] Aldaya M.M., Muñoz G., Hoekstra A.Y., 2010. Water footprint of cotton, wheat and rice production in Central Asia. Value of Water Research Report Series No. 41, UNESCO-IHE Institute for Water Education, Delft, Netherlands, pp. 38.Accessed at http://waterfootprint.org (07-27-2016)

[24] Siebert S.,Portmann F.T., Döll P., 2010.Global patterns of cropland use intensity. Remote Sensing2, 1625-1643.

[25] Edlinger J., Conrad C., Lamers J.P.A., Khasankhanova G., Koellner T., 2012. Reconstructing the spatio-temporal development of irrigation systems in Uzbekistan using Landsat time series. Remote Sensing 4(12), 3972-94.

[26] Tischbein B., Manschadi A.M., Conrad C., Hornidge A.K., Bhaduri A., ul Hassan M., Lamers J.P.A., Awan U.K., Vlek P.L.G., 2013. Adapting to water scarcity: constraints and opportunities for improving irrigation management in Khorezm, Uzbekistan. Water Science & Technology: Water Supply 13(2), 337. doi:10.2166/ws.2013.028.

[27] SIC-ICWC. 2014. Regional Information System on Water and Land Resources in the Aral Sea Basin (CAREWIB).http://www.cawater-info.net.

[28] Conrad C., Dech S.W., Hafeez M., Lamers J.P.A., Tischbein B., 2013. Remote sensing and hydrological measurement based irrigation performance assessments in the Upper Amu Darya Delta, Central Asia.Physics and Chemistry of the Earth 61-62. Elsevier Ltd: 52-62.doi:10.1016/j.pce.2013.05.002.

[29] Molden D., Sakthivadivel R., 1999. Water accounting to assess use and productivity of water. International Journal of Water Resources Development 15(1-2), 55-71.