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Irrigation Performance Assessment Using Satellite Remote Sensing: Insights from Tajikistan[1]

KEY POINTS

- From this study on the Chubek Irrigation System in Tajikistan, a new relative irrigation performance index—water use ratio (WUR)—proved effective and reliable given favorable remote sensing conditions and climatic and cropland data.
- The WUR is particularly suitable for river basins and large irrigation systems in developing countries where data on irrigation canal flow are not available or limited.
- A quantitative performance index—irrigation consumptive use coefficient (ICUC)—was also applied. But this requires reliable canal flow data, which were unavailable in the case presented.
- It is highly recommended that both WUR and ICUC are used for monitoring and evaluating irrigation performance at project completion and for future water management.
- For reliable canal flow data, flow recording devices are needed. Strong institutional arrangements, trained staff, and resources for essential equipment are also required.
- Results of the study provide a valuable guide for assessing irrigation system performance using remote sensing data as well as modernizing existing systems and designing new ones.

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INTRODUCTION

The use of remote sensing data in design, monitoring, and evaluation of irrigation systems is becoming popular due to rapid advances in remote sensing technology, ease of access to data, and decreasing costs of obtaining and processing the data. Satellite spatial resolution as fine as 30 meters is available and the remote sensing data, combined with adequate cropland information, can provide detailed analyses not otherwise available. The technology is also particularly suitable for river basins and large irrigation systems in developing countries where available resources are generally not enough for field surveys, and data collection and reliable recorded data are limited.

This study used remote sensing satellite data and field observations to assess the irrigation performance of the Chubek Irrigation System (CIS) in Tajikistan, as part of the Water Resources Management in Pyanj River Basin technical assistance (TA) project financed by the Asian Development Bank (ADB).[2] The map on p. 2 provides information about the components of the CIS and satellite remote sensing data from the study.

ASSESSMENT OBJECTIVES

(i) Develop and validate a way to assess the performance of the irrigation system as a whole and on-farm, using satellite remote sensing and field data.

(ii) Collect baseline data for 2014 to show the irrigation efficiency of the system and optimal level of on-farm irrigation based on the new methodology.

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[1] This brief was based on the “Irrigation Performance Assessment Using Satellite Remote Sensing – Tajikistan Case Study,” which was prepared by Ryutaro Takaku, principal water resources specialist, Southeast Asia Department, ADB; Akihiro Shimasaki, water resources specialist, Central and West Asia Department (CWRD), ADB; Hideyuki Fuji, remote sensing specialist, Remote Sensing Technology Center of Japan; Masahiro Tasumi, professor, Faculty of Agriculture, University of Miyazaki; and Yusuke Muraki, engineer, Japan Aerospace Exploration Agency. Jay Maclean, communications specialist (independent consultant), prepared the brief with support from Noriko Sato, natural resources specialist and Kristine Joy Villagracia, operations assistant, CWRD, ADB. The following ADB staff provided technical reviews and comments: Yaozhou Zhou, principal water resources specialist, CWRD; Raza Farrukh, unit head, project administration, CWRD; and Jelle Beekma, senior water resources specialist, Sustainable Development and Climate Change Department. Yasmin Siddiqi, director, Environment, Agriculture and Natural Resources Division, CWRD, ADB provided overall technical guidance in preparing this brief.

[2] ADB. 2020. Tajikistan: Water Resources Management in Pyanj River Basin. https://www.adb.org/projects/47181-001/main.

Box 1: Chubek Irrigation System

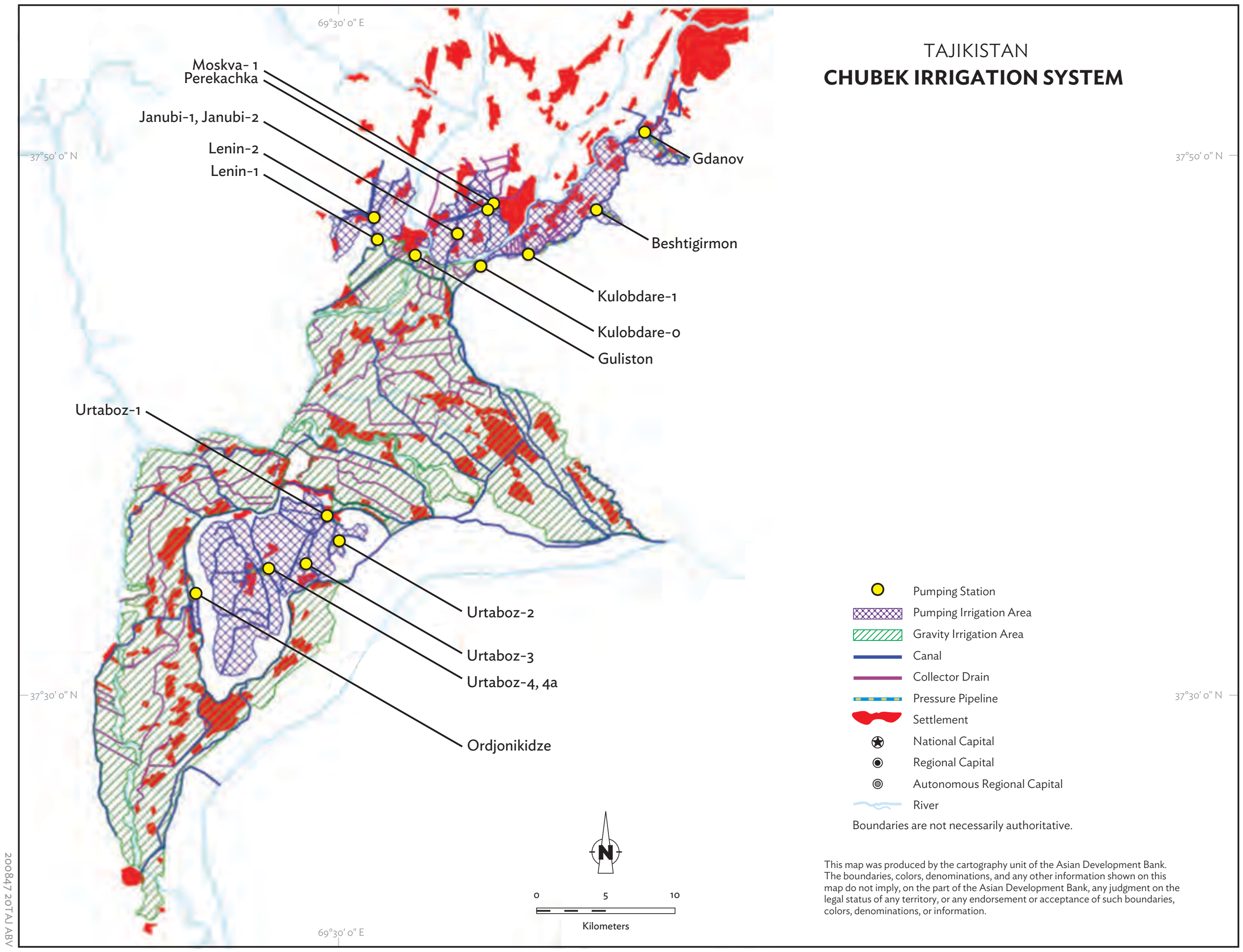
The Chubek Irrigation System in Khatlon Province of Tajikistan, covering about 50,000 hectares on the right bank of Pyanj River, was constructed during 1950–1987 to supply water in Hamadoni, Farkhor, Vose, and Kulob districts. Wheat occupies 50% and cotton occupies 46% of the area. Other crops include vegetables, fodder, and orchard trees. Wheat is grown as a single crop and in double crop rotation.

Water is supplied by a combination of a gravity system and 20 sets of pumping units. Mostly dilapidated pumps feed about 30% of the irrigated system. Poor maintenance resulted in significant loss of farm productivity, largely due to high and abrasive sediment intake, and insufficient irrigation water reaching the crops.

Source: ADB. 2015. *Water Resources Management in Pyanj River Basin* (TA 8647-TAJ) Consultant's Report: Chubek Irrigation Performance Assessment using Satellite Remote Sensing Data. Unpublished.

Chubek Canal main gates. The gate controls inflow from Pyanj River to Chubek Irrigation System (photo by Project Implementation Group, Agency for Land Reclamation and Irrigation).

Map of Chubek Irrigation System



Source: ADB. 2015. *Water Resources Management in Pyanj River Basin* (TA 8647-TAJ) Consultant's Report: Chubek Irrigation Performance Assessment using Satellite Remote Sensing Data. Unpublished.

ASSESSMENT METHODOLOGY

The Remote Sensing Technology Center of Japan conducted the study using satellite data from two sources: (i) Moderate Resolution Imaging Spectroradiometer (MODIS) distributed by the National Aeronautics and Space Administration (NASA) Land Processes Distributed Active Archive Center, United States Geological Survey (USGS) Earth Resources Observation and Science (EROS) Center; and (ii) Landsat 8 data collected from USGS. Topographic and meteorological data and irrigation and cropland information were collected from the field and from literature sources. The TA project team did the fieldwork during the 2014 cropping season.

Remote sensing data and field data were analyzed to:

(i) prepare crop cover maps for the whole project area and for each project district, and calculate seasonal changes in indexes;
(ii) calculate monthly reference crop evapotranspiration, crop coefficients, and optimal and actual evapotranspiration indexes for various crops grown in the project area; and
(iii) estimate monthly irrigation water delivered separately for gravity-fed and pump-fed areas.

The irrigation performance assessment used three indexes:

(i) **Actual evapotranspiration** rate in the cropland, computed from a reference evapotranspiration rate for the site, which is based on a hypothetical, uniform grass surface with adequate water at a specific location and time of year, and meteorological data; the reference rate represents the evaporative power of the atmosphere.
(ii) **Irrigation optimality**, measured as the water use ratio (WUR)—a new concept developed in this study—defined as the ratio of actual to optimal evapotranspiration (Box 2).
(iii) **Irrigation efficiency** of the overall irrigation system, the ratio of amount of water consumed by the crop to amount of water supplied through irrigation, evaluated using the irrigation consumptive use coefficient (ICUC), which is defined as the ratio of volume of irrigation water consumed by the system to the total volume of irrigation water applied to the system over a specified time period.

Box 2: Water Use Ratio

The water use ratio (WUR), the ratio of actual to optimal evapotranspiration, is calculated from satellite remote sensing data at the on-farm level (= MODIS satellite footprint level, 1–2 kilometers), where optimal evapotranspiration is defined as the product of the reference evapotranspiration and crop coefficient—a variable that represents actual evapotranspiration for a crop at each growth stage under ideal conditions; its value varies with crop type and growth stage. The Food and Agriculture Organization of the United Nations (FAO) published crop coefficient values for many crop types at their different growth stages..

When more than one crop type occurs within a data pixel (a “mixel”), the contribution of each crop type to total evapotranspiration is obtained by summation; if the area ratio of crop acreage in the mixel is available, the estimate can be refined as an area-weighted average.

Source: Authors; and R. G. Allen et al. 1998. Crop Evapotranspiration: Guidelines for Computing Crop Water Requirements. *FAO Irrigation Drainage Paper* No. 56. Rome: FAO.

MAIN FINDINGS

Data quality. The quality of crop cover maps and the WURs prepared from satellite data and field information was found to be adequate to identify various individual crops and crop mixes, as well as areas and periods of moisture stress, and the extent of stress.

Water flow records were obtained for various locations along the CIS, but the gauging stations were not maintained and no current meters were working; thus, flow ratings have not been updated. Measurements of discharge from the main irrigation canal in September 2015 showed the discharge rate to be only 63% of that reported in records of the Agency for Land Reclamation and Irrigation (ALRI), which observed similar levels of over-registering in past years.

The area covered by irrigation in the CIS fell to an estimated 43,000 hectares, about 86% of the design conditions, as a result of the inadequate maintenance since its commissioning.

Irrigation efficiency assessment using the WUR. The WUR has a maximum value when actual evapotranspiration is at the optimal level; it also assumes this level provides maximum yield (as dry matter). The assumption is supported by the strong relationship determined in this study between the WUR and the normalized difference vegetative index (NDVI), an indicator based on satellite-derived chlorophyll measurements of the amount of vegetation, which has a positive relationship with dry matter production of plants.

Using MODIS data, the WUR distribution maps can be made daily throughout the crop season (April–October), as well as composite maps for the rainy and dry seasons for the system as a whole, for the gravity and pumped zones.

In 2014, the WURs remained above 60% during the spring rainy season. During the dry summer, the WURs were low in both the gravity and pump zones; and the WURs in the pump zone (32%) were lower than those in the gravity zone (45%), attributed to insufficient delivery of irrigation water against the water requirements of the crops due to the dilapidated pumps.

Irrigation efficiency assessment by ICUC. The ICUC values were calculated for the crop season as the ratio of the amount of actual evapotranspiration estimated from satellite remote sensing data, with meteorological data as the volume of irrigation water consumed by the system (the numerator), and the volume of canal flow and pumped water data measured and recorded by the ALRI as the volume of irrigation water applied to the system (the denominator); uniform precipitation over the area is assumed. The ICUC values were calculated for the system, district, and lower levels of irrigation command. The ICUC values in the gravity zones were found to be higher than in the pump zones, but varied widely from one pumping station to the next.

The volume of irrigated water can only be estimated from the monitored and measured irrigation data of the system. Thus, quality of the ICUC strongly depends on the quality of the irrigation data collected. Other sources of error are (i) under- or overestimation of the total area where irrigated water is applied; (ii) error in estimating evapotranspiration, either because the underlying crop coefficient algorithm contains some errors or the weather data are poor; and (iii) faulty estimation of the effect of precipitation on irrigation performance.

Irrigation efficiency is an important parameter for assessing present water delivery performance and use, and designing the irrigation system to meet crop water requirements under different conditions. Remote sensing data give fairly reliable estimates of the volume of irrigation water consumed by the system, but actual flow data are required to calculate the irrigation efficiency quantitatively as data on the volume of irrigation water applied to the system. The reliability of results will be no better than the reliability of the flow records. The overall estimated irrigation efficiency of the CIS using water flow data recorded in the ALRI was 20%–30%. This should be adjusted upward since actual water flows are only about 60% of the rates shown in the ALRI flow records, suggesting an irrigation efficiency using the ICUC of 30%–40%. This range broadly agrees with the irrigation efficiency estimated using the WUR (67% during the rainy season, April–May; and 42% in the dry season, July–August).

CONCLUSION

The poor state of flow records in the CIS has serious implications for future management of the system. Estimation of water requirements for future cropping patterns and intensities should not depend on the reliability of flow data; estimates will have to be based on agroclimatic factors rather than on historic records.

The water use ratio. The novel WUR index was found to be effective where ground-based information is limited. The WUR concept is based on *relative* evapotranspiration rates, which are more robust in terms of estimation error than absolute units. Furthermore, the combination of the NDVI and the WUR, which are independent of each other, provides information about field water management and its impact on crop production. The WUR can also be used for scheduling irrigation system operation, detection of bottlenecks in water delivery, and comparative assessment of water-use efficiency between farmlands in each crop growing season. The optimal evapotranspiration rate can be calculated when the cropping schedule is planned. Water demand can then be estimated by assuming a value of the WUR. However, the effectiveness and reliability of the WUR in the study relied on several factors, without which the applicability of the WUR should be critically examined:

(i) few cloudy days in the area, which allowed maximum availability of satellite remote sensing data;
(ii) low precipitation, which allowed reliable satellite data without rainfall bias;
(iii) availability of daily meteorological data near the target area;
(iv) the irrigation method—furrow, not flooded irrigation; and
(v) cropland information, such as crop calendar and crop cover map, collected in the field survey to validate and adjust the outputs from satellite data and to improve the accuracy of optimum crop coefficient curves for each of the major crops.

The irrigation consumptive use coefficient. The ICUC is an effective *quantitative* indicator of irrigation performance. However, in the CIS, its values were unreliable because of unreliable field canal flow data. It is strongly recommended that quality of field data be determined before initiating an assessment study and to install, if necessary, flow measurement devices at key sections and in each pump to improve the monitoring and recording of discharge data.

It is also highly recommended that both the WUR and the ICUC be used for monitoring and evaluation of irrigation performance at project completion and for future water management by setting up a user-friendly monitoring and evaluation system through satellite data archiving and web-based information systems to browse the data archive and to monitor the irrigation status of the system and on farm.

Resource needs. The current state of water flow records in the CIS highlights the need for strong and properly equipped institutions with trained staff to make regular observations, analyses, and recording of observed data. Also vital are adequate resources for proper field equipment for discharge observation and training of staff.

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Asian Development Bank
6 ADB Avenue, Mandaluyong City
1550 Metro Manila, Philippines
Tel +63 2 8632 4444
Fax +63 2 8636 2444

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