**DATA ARTICLE**

**Water use efficiency data from 2000 to 2019 in measuring progress towards SDGs in Central Asia**

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**ABSTRACT**

Central Asia, located in the hinterland of the Eurasian continent, is characterized with sparse rainfall, frequent droughts and low water use efficiency. Limited water resources have become a key factor restricting the sustainable development of this region. Accurately assessing the efficiency of water resources utilization is the first step to achieve the UN Sustainable Development Goals (SDGs) in Central Asia. However, since the collapse of the Soviet Union, the evaluation of water use efficiency is difficult due to low data availability and poor consistency. To fill this gap, this paper developed a Water Use Efficiency dataset (WUE) based on the Moderate Resolution Imaging Spectroradiometer (MODIS) Gross Primary Production (GPP) data and the MODIS evapotranspiration (ET) data. The WUE dataset ranges from 2000 to 2019 with a spatial resolution of 500 m. The agricultural WUE was then extracted based on the Global map of irrigated areas and MODIS land use map. As a complementary, the water use amount per GDP was estimated for each country. The present dataset could reflect changes in water use efficiency of agriculture and other sectors. The published data are available at [http://www.dx.doi.org/10.11922/sciencedb.j00076.00012](http://www.dx.doi.org/10.11922/sciencedb.j00076.00012).

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1. Introduction

Central Asia is a collective term denoting the five countries of Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan and Uzbekistan. Located in the hinterland of Eurasia, Central Asia spans an area of 402.8 × 10⁴ km² (46°29’~87°18’E, 35°07’~55°26’N) and supports 66.4 million population (Figure 1). Central Asia is one of the most arid regions in the world, featured with fragile mountain-oasis-desert ecosystems, uneven water distribution and low water use efficiency (Chen, Li, Fang, & Li, 2018; Li, Fang, Chen, Duan, & Mukanov, 2020). The available freshwater resources mainly come from rainfall, glaciers and snowmelt in the upstream rivers, which are mainly originated from Kyrgyzstan and Tajikistan; while little water is generated in the downstream area in Uzbekistan and Turkmenistan (Hagg, Hoelzle, Wagner, Mayr, & Klose, 2013; Wang, Chen, & Li et al., 2020a; Zhang et al., 2019).

With climate change and excessive water use in recent decades, water-related disputes have intensified. The upstream and downstream countries have great conflicts in the

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allocation and management of water resources, and the fragile ecological environment has been damaged, especially for the Aral Sea region. Large-scale reclamation and construction of water conservancy facilities in the basin have led to a sharp retreat of the Aral Sea, with its surface area shrinking by 90% (Wang et al., 2020a). The river bed of the Aral Sea dried up and the aquatic ecosystem seriously degraded, making the Aral Sea a world-renowned “Ecological Disaster Area” (Micklin, 2016). Water shortage has become a key factor limiting the sustainable development of this region, especially for the downstream agricultural countries of Uzbekistan and Turkmenistan. These two downstream countries produce much less water than the upstream countries, mainly relying on inbound water resources to satisfy their economic needs (Chen et al., 2018).

Low water use efficiency is a main factor leading to water shortage in Central Asia. Therefore, accurately assessing the efficiency of water resources utilization of each sector is the first step to achieve sustainable development goals (SDGs) in Central Asia, and it can provide scientific references for regional water resources allocation and management.

Based on UN WATER indicators, country-scale Water Use Efficiency (WUE) is defined as the value added per unit of water used, expressed in USD/m³, over time of a given major economic sector: agriculture, industry and services. It is calculated as the sum of water-use efficiency (WUE) of each of these three sectors, weighted according to the proportion of water used by each sector over the total uses. Since 2020, SDG 6.4.1 on water use efficiency was upgraded from tier II to tier I due to data availability from a critical mass of countries. However, these data are mostly unavailable and some statistics are biased due to low data inconsistency in Central Asia. It is urgent to use remote sensing data to detect changes in water use efficiency as a complement to the statistical data. As agriculture is the primary sector in Central Asia and about 90% of water abstractions are used by the agricultural sector (Table 1; Unger-Shayesteh et al., 2013), agricultural WUE is important in measuring regional WUE.
Table 1. Water use amount in agriculture, industry and services together with GDP in 2012 in Central Asian counties.

| Countries     | Water use amount in industry $10^9$m³ | Water use amount in Services $10^8$ m³ | Water use amount in agriculture $10^9$ m³ | GDP $10^8$ USD |
|---------------|--------------------------------------|----------------------------------------|------------------------------------------|---------------|
| Kazakhstan    | 62.64 (30%)                          | 8.78 (4%)                              | 140.01 (66%)                             | 2080          |
| Kyrgyzstan    | 3.36 (4%)                            | 2.24 (3%)                              | 74.47 (93%)                              | 66            |
| Tajikistan    | 4.08 (4%)                            | 6.47 (6%)                              | 104.40 (90%)                             | 76            |
| Turkmenistan  | 8.39 (3%)                            | 7.55 (3%)                              | 263.60 (94%)                             | 352           |
| Uzbekistan    | 15.00 (3%)                           | 41.00 (7%)                             | 504.00 (90%)                             | 518           |

Agricultural WUE is normally defined as the ratio of carbon assimilation or productivity to water loss, which is a common indicator to investigate changes in water use efficiency of terrestrial ecosystems (Baldocchi & Wilson, 2001). Generally speaking, WUE is the ratio of plant photosynthesis to transpiration, involving different carbon and water processes. It may therefore respond differently to biological changes, climate change and crop patterns or irrigation schemes (Zeri, Hussain, Anderson-Teixeira, DeLucia, & Bernacchi, 2013). Previous studies have evaluated agricultural WUE at field scale, for example, water productivity of cotton and rice in the Syr River Basin (Abdullaev & Molden, 2004), crop evapotranspiration in the Fergana Basin (Conrad et al., 2013), agricultural WUE of different crops under different irrigation conditions in the Aral Sea Basin (Lee & Jung, 2018). They found that the utilization efficiency of water resources in Central Asia was generally lower than that in other Asian countries, and crop yield and WUE could be improved through rational selection of crop types and irrigation methods. Regional investigations on WUE were carried out in many places around the world (e.g. the semi-arid northwestern China by Wu, Zhou, Wang, Li, and Zhong (2015); the United States by Ahmadi, Ahmadalipour, Tootle, and Moradkhani (2019) and Lu and Zhuang (2010)), but seldom investigations focused on the WUE changes in Central Asia (Zou, Ding, Welp, Huang, & Liu, 2020).

Some researchers released water use related datasets, but direct water use efficiency datasets in Central Asian countries are not currently available. For example, (1) ECOSTRESS Water Use Efficiency Daily L4 Global 70 m dataset, which is generated according to the Priestley-Taylor Jet Propulsion Laboratory (PT-JPL) algorithm, only covers the contiguous United States since 2018–07-09. (2) The Global Gridded Monthly Sectoral Water Use Dataset for 1971–2010 (Huang et al., 2018) is a global monthly, gridded (0.5 degree), sectoral water withdrawal data set that distinguishes six water use sectors: irrigation, domestic, electricity generation, livestock, mining, and manufacturing. But this dataset does not include the product/profit or water use efficiency information.

As regional WUE dataset in Central Asia is currently not available, an agricultural WUE dataset was produced based on MODIS ET and GPP data to understand changes in agricultural WUE. To evaluate SDG 6.4.1 (Time-series water use efficiency Tier I) of each country in Central Asia, another indicator of water consumption per 10,000 USD GDP of five countries was also constructed. With these two datasets, the agricultural WUE and overall WUE could be reflected. These datasets could help us understand the development and utilization of water resources in Central Asia and is of great significance to the rational allocation of water resources in this region. The research can provide new sights for the formulation of water resources policies in Central Asian countries and provide a scientific reference for the “Silk Road” construction.
2. Methods

The agricultural WUE dataset of Central Asia was produced based on MODIS Evapotranspiration (ET) data and MODIS Gross Primary Productivity (GPP) data (Figure 2). MODIS is one of the main sensors mounted on Terra and Aqua satellites. There are many standard MODIS data products that scientists are using to study global change. These data will improve our understanding of global dynamics and processes occurring on the land.

The MOD16 global evapotranspiration product can be used to calculate regional water and energy balance and soil moisture status. Using long-term ET data, it is possible to quantify the evolution of regional water use efficiency and land surface energy changes. Therefore, MOD16A2 (MODIS/Terra Evapotranspiration 8-Day Level-4 Global 500 m SIN Grid) was used as the input data. The algorithm used for the MOD16A2 data product collection is based on the logic of the Penman–Monteith equation, which includes inputs of daily meteorological reanalysis data along with MODIS remotely sensed data products such as vegetation property dynamics, albedo, and land cover (Mu, Zhao, & Running, 2011, 2013). These data products covering Central Asia region include 14 tiles and 12 issues of each year (Table 2) with a total of 3360 files for ET. These data were obtained from the MODIS Global Evaporation Project dataset, managed by the Land Processes Distributed Active Archive Center (LP DAAC) at the USGS Earth Resources Observation and Science (EROS) Center (https://modis.gsfc.nasa.gov/data/dataprod/mod16.php).

MOD17 is part of NASA's Earth Observation System (EOS) program and is the first satellite-driven data set to monitor vegetation productivity on a global scale. The MOD17A2H (MODIS/Terra Gross Primary Productivity 8-Day L4 Global 500 m SIN Grid) was used as input data in producing the WUE dataset. It is a cumulative 8-day composite of values with 500 meters (m) pixel size based on the radiation use efficiency concept (Running, Mu, & Zhao, 2015). This dataset is used to present added plant carbon.

![Flow chart of the processing procedure of agricultural WUE and water consumption per GDP in Central Asia](image)

**Figure 2.** Flow chart of the processing procedure of agricultural WUE and water consumption per GDP in Central Asia.
The MODIS ET and GPP products were pre-processed in GIS environment separately (GCS WGS 1984) with image projection, mosaic, aggregation and image clipping. Firstly, the preprocessing of MODIS images is achieved by using MODIS Reprojection Tool (MRT) to interpret and generate .prm files, and then these .hdf files were converted to .tif images using code batch processing. Finally, the 8-day ET data and GPP data were aggregated to summer seasons (day 153 to day 248) to calculate crop water use efficiency (WUE) by dividing GPP by ET (Equation 1).

\[
WUE = \frac{GPP}{ET}
\]

where WUE (g C·kg\(^{-1}\) H\(_2\)O) is the water use efficiency of terrestrial ecosystems; GPP (g C·m\(^{-2}\)) is the total primary productivity of terrestrial ecosystems; ET (kg H\(_2\)O·m\(^{-2}\)) is the actual land surface evapotranspiration.

The MODIS land use data were derived from the Global Land Cover Characterization data under the International Geosphere-Biosphere Program (IGBP) (http://modis.gsfc.nasa.gov/data/dataprod/mod12.php). From these data, a routine integrated classification of land use/cover change (LUCC) characteristics was obtained based on feature fusion processes. By combining the Global map of irrigated areas from AQUASTAT Global Information System on Water and Agriculture (http://www.fao.org/nr/water/aquastat/irrigationmap/index10.stm), the agricultural area of Central Asia was determined.

Water consumptions per 10,000 US Dollar GDP of the five countries were calculated by dividing GDP by water consumption. This indicator is often used in measuring overall water use efficiency (Xu et al., 2020). The GDP data and water use data were derived from the statistical website, which were indicated in “Data records” section.

Table 2. Date files used to generate the WUE dataset in Central Asia.

| Dataset (2 datasets) | Column and row (14 tiles) | Year (20 years) | Start date (Julian day, 8-day composite) |
|----------------------|---------------------------|----------------|----------------------------------------|
| MOD16A2               | H20V03                    | 2000           | 153                                    |
| MOD17A2H              | H20V04                    | 2001           | 161                                    |
|                      | H21V03                    | 2002           | 169                                    |
|                      | H21V04                    | 2003           | 177                                    |
|                      | H21V05                    | 2004           | 185                                    |
|                      | H22V03                    | 2005           | 193                                    |
|                      | H22V04                    | 2006           | 201                                    |
|                      | H22V05                    | 2007           | 209                                    |
|                      | H23V03                    | 2008           | 217                                    |
|                      | H23V04                    | 2009           | 225                                    |
|                      | H23V05                    | 2010           | 233                                    |
|                      | H24V04                    | 2011           | 241                                    |
|                      | H24V05                    | 2012           |                                         |
|                      | H25V05                    | 2013           |                                         |
|                      |                           | 2014           |                                         |
|                      |                           | 2015           |                                         |
|                      |                           | 2016           |                                         |
|                      |                           | 2017           |                                         |
|                      |                           | 2018           |                                         |
|                      |                           | 2019           |                                         |
3. Data records

This dataset aims to evaluate SDG indicator 6.4.1, i.e., change in water-use efficiency over time in Central Asia. It consists of two sub-datasets. One is the summer WUE dataset from 2000 to 2019 and the other is the water use amount per 10,000 USD GDP for the five countries from 1997 to 2017.

The domain of the WUE dataset covers the land areas of the five Central Asian countries, which ranges from 35°07’N to 55°26’N in latitude and from 46°29’E to 87°18’E in longitude, covering an area of $402.8 \times 10^4$ km$^2$ at a spatial resolution of 500 m. This dataset reflects long-term changes in summer WUE. Each raster file corresponds to 1 year. For example, the file WUE-CentralAsia2000.tif refers to summer WUE in Central Asia in 2000.

The nation-scale water use efficiency was represented using total water use amount per 10,000 USD GDP. The GDP data in the five Central Asian Countries were from the World Bank (https://data.worldbank.org/country). And water use amount data were from the Food and Agriculture Organization of the United Nations (http://www.fao.org/nr/water/aquastat/data/query/index), the United Nations Data Retrieval System (http://data.un.org/) and the National Statistical Committee of the Kyrgyz Republic (http://www.stat.kg/en/statistics/selskoe-hozyajstvo/).

In addition, the agricultural area, i.e. the distribution of crop land of Central Asia, was produced by merging the MCD12Q1 land cover data (in year 2010) and the global irrigation dataset (“Global Map of Irrigation Areas” version 5, around the year 2005 with a resolution of 5 minutes).

4. Technical validation

Owing to measurement difficulties, few studies have systematically compared temporal patterns of WUE changes across Central Asia and there are no long-term flux stations in Central Asia at the FLUXNET (Ibragimov et al., 2007; Zou et al., 2020). To validate the WUE dataset, we firstly validated the MOD16A2 and MOD17A2H data by comparing to FLUX stations and other ET or GPP measurements at specific regions, and then explained the reliability of the WUE dataset.

The MOD16 ET has been validated with ET measured at eddy flux towers and ET estimates from 232 watersheds worldwide (Mu et al., 2013) and this dataset has a good representation of croplands and grasslands (Khan, Liaqat, Baik, & Choi, 2018). For the Central Asia region, as there are no sufficient eddy flux stations in crop land, the estimated ET was compared to crop water requirement. For example, the annual ET of the well-irrigated Fergana region is 288 mm, which is lower than the crop water requirement of cotton (637 mm, Conrad et al., 2013) partly due to the heterogeneous agricultural practice, water shortage or mixed pixel. For desert area and grass area in Central Asia, two eddy covariance measurements at KZ-Ara (61.08° E, 45.97° N) and KZ-Bal (76.65° E, 44.57° N) were used, respectively, to evaluate the MOD16A2 of typical desert area and grassland area. The summer MODIS ET values were 13.3 mm and 77.2 mm at the corresponding grids in 2012, which are lower than the measure values of 144 mm and 468 mm, respectively, at the two sites (Wang et al., 2014). The underestimation maybe exaggerated due to the mix pixels as the surrounding area of these two sites are desert lands. What worth noting is that the spatial variations of MOD16A2 are reliable with the
highest ET observed in cropland, followed by grassland, and desert land has the lowest ET, which is consistent with measurements.

The accuracy and reliability of MODIS-derived GPP have been validated in many regions by using the eddy covariance observed GPP around the world (Turner et al., 2006; Wang et al., 2017; Zhao, Heinsch, Nemani, & Running, 2005). For the arid and semi-arid regions of China, the current MOD17A2H GPP algorithm could, on the whole, capture the broad trends of GPP at eight-day time scales for most investigated sites (Wang, Li, Ma, & Geng, 2019). However, there may be some biases in the absolute GPP value. Previous results indicated that MOD17A2H tended to overestimate GPP at low productivity sites (Turner et al., 2006) but showed an underestimation in some ecosystems in the arid region, especially for the irrigated cropland and forest ecosystems (Wang et al., 2019). We further examined the GPP using eddy covariance measurement at a desert site (KZ-Ara, 61.08° E, 45.97° N) and a grassland site (KZ-Bal, 76.65° E, 44.57° N). The MODIS GPP values are 40.1 g C/m² and 95.5 g C/m², respectively, which are higher than the measurements, which equaled to 20.15 g C/m² and 75.58 g C/m² in summer 2012, respectively (Wang et al., 2014). Though the MOD17A2H may be biased in reflecting the accurate value of GPP in Central Asia region, MOD17A2H could preserve the changing trends with time.

The WUE dataset shows consistent spatial variation similar to data from the tower network globally (Tang et al., 2014). However, the sites in FLUXNET are extremely rare in Central Asia and most field-scale studies focus on different irrigation regimes, which cannot be used to validate this dataset (Ibragimov et al., 2007). Therefore, the direct validation of WUE is somewhat impossible here. From the above assessment of ET and GPP, we could assume the time-varying WUE data is reliable, which could be inferred from its sensitive responses to drought (Zou et al., 2020). The absolute accuracy can also vary from region-to-region. Thus, users are encouraged to use this dataset in time-varying assessment studies. In conclusion, the WUE dataset based on MOD16A2 and MOD17A2H is reliable when coming to the relative changes in water use efficiency.

5. Results and analysis

Agriculture is a major water-consuming sector in Central Asia, accounting for 66% to 94% of total water use (Table 1). Except for Kazakhstan, the proportions of agricultural water-consuming in the other four countries are more than 90%, which are much higher than the world's average (71%) (Lee & Jung, 2018). Water consumption in Central Asian countries for municipal and industry sectors is far less than that for agriculture. For recent decades, the proportion of agricultural water consumption has gradually decreased from 91.89% in 1997 to 87.61% in 2014, and the proportion of industrial and municipal water consumption has gradually increased (Wang, Chen, & Li et al., 2020b).

This dataset is designed to understand changes in water use efficiency in Central Asian countries. Based on the total primary productivity (GPP) and evapotranspiration (ET) of the cultivated land in the five Central Asian countries, the paper proposes a dataset of summer WUE and analyzes the changes in the ecosystem WUE of the cultivated land in the five Central Asian countries from 2000 to 2019. Spatially, WUE in mountainous areas, the vast areas of northern Kazakhstan are generally low. While in regions such as the plain area around the Balkhash Lake Basin and Fergana Valley, the WUE is generally high. WUE decreased significantly during 2000-2019 especially for the central Kazakhstan, the
Balkhash Lake Basin and the southeastern Turkmenistan (Figure 3). For the cultivated land, WUE showed an overall downward trend from 2000 to 2019. Specifically, Uzbekistan and Turkmenistan show the most significant downward trends, mainly because their irrigation facilities are relatively backward and the cropland relies on furrow irrigation leading to the low crop yield and low utilization efficiency of water resources. In Kazakhstan, however, irrigation technology has been improved in recent years, resulted in an increase in water use efficiency of irrigated land (Figure 4). What worth noting is that WUE has a significant increase in the northern part of Kazakhstan (featured with rain-fed wheat), which may be driven by the continuous warming. In addition, we should note that the ecosystem WUE is sensitive to drought across Central Asia and previous research indicated that the WUE showed a negative correlation with drought during the drought period, while a positive correlation between WUE and drought was found in the post-drought period (Zou et al., 2020). The droughts could influence the interpretation of the agricultural WUE to some extent.

To understand the water use efficiency of agriculture and other sectors, the water use amount per GDP of the five Central Asian countries were calculated based on statistical data. The average annual water consumption per 10,000 United States dollars (USD) GDP is high in Tajikistan (15,845.97 m³) and Kyrgyzstan (12,551.10 m³), and is the lowest in Kazakhstan (1,214.88 m³). It is indicated that water use amount per GDP showed a significant downward trend from 1997 to 2017 for these five countries. For example, Tajikistan and Turkmenistan dropped by 11.22 × 10⁴ m³ and 8.93 × 10⁴ m³ per 10,000 USD GDP during 1997 to 2017, respectively. The overall water use efficiency of the five Central Asian countries has shown an increasing trend in the past two decades (Figure 5). Technological progress and a decline in the proportion of agricultural water consumption have contributed to the reduction in water consumption per GDP.
Based on the above analysis, some measures are suggested to improve WUE to achieve SDG 6. As the WUE increase in Central Asia is mainly attributed to the increase in WUE of industry and services, the water use proportions of industry and services should increase to generate more economic benefits. Positive measures should also be taken to speed up the process of industrial structure restructuring and upgrading and to increase the reuse rate of water resources. On the other hand, as the agricultural WUE is decreasing in most regions, improving the planting structure of crops and reducing the areas of water-intensive crops appropriately should be considered, especially for Uzbekistan and Turkmenistan. The irrigation and transportation efficiency should also be improved to reduce water waste in channel systems. It is also suggested to develop advanced agricultural and industrial water-saving technologies to improve the utilization efficiency of water resource (Wang et al., 2020b).

Figure 4. Temporal variations of agricultural WUE in Central Asia from 2000 to 2019. The shaded area shows the standard deviation of WUE.
6. Usage notes

The data set contains 20 raster files, one vector file and two Excel files. The raster file is named with the data type and year. For example, *WUE-CentralAsia2000.tif* is the water use efficiency map of Central Asia in 2000. One file corresponds to 1 year from 2000 to 2019. The vector shapefile is the distribution of crop land of Central Asia ("Cropland_Central_Asia"), produced by the MCD12Q1 landuse data and the global irrigation dataset. One excel file (named "WUE changes of Central Asia.xlsx") contains five columns, and each column shows the agricultural summer WUE values in Central Asia from 2000 to 2019 and the other excel file ("Water use amount per GDP.xlsx") contains 5 columns with the total water use amount per 10,000 USD GDP of each country from 1997 to 2017. Users can extract the WUE value for the user-defined area.

Data Availability Statement

The data that support the findings of this study are openly available at http://www.dx.doi.org/10.11922/sciencedb.j00076.00012.

Disclosure statement

No potential conflict of interest was reported by the authors.

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Xuanxuan Wang received the B.E.S. degree in geography science from Ludong University. Currently, she is pursuing the Ph.D. degree in physical geography at Xinjiang Institute of Ecology and Geography, Chinese Academy of Sciences. Her research area is Central Asia and she involved herself in the issues related to development and utilization of water resources, alleviation of water conflicts and eco-hydrological processes and etc. She quantitatively analyzed the water development potential and water security of Central Asia by different statistical methods, and further put forward suggestions on how to effectively manage water resources in the future. They focus on the water and ecological conditions around the Aral Sea and the surrounding areas. Her work could provide significant evidence on future water resources management in Central Asia.

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References

Abdullaev, I., & Molden, D. (2004). Spatial and temporal variability of water productivity in the Syr Darya Basin, Central Asia. *Water Resources Research, 40*(8), 379–405.

Ahmadi, B., Ahmadalipour, A., Tootle, G., & Moradkhani, H. (2019). Remote sensing of water use efficiency and terrestrial drought recovery across the contiguous United States. *Remote Sensing, 11*(6), 731.

Baldocchi, D., & Wilson, K. B. (2001). Modeling CO2 and water vapor exchange of a temperate broadleaved forest across hourly to decadal time scales. *Ecological Modelling, 142*(1–2), 0–184.

Chen, Y. N., Li, Z., Fang, G. H., & Li, W. (2018). Large hydrological processes changes in the transboundary rivers of Central Asia. *Journal of Geophysical Research Atmosphere, 123*(10), 5059–5069.

Conrad, C., Rahmann, M., Machwitz, M., Stulina, G., Paeth, H., & Dech, S. (2013). Satellite based calculation of spatially distribut ed crop water requirements for cotton and wheat cultivation in Fergana Valley, Uzbekistan. *Global & Planetary Change, 110*(4), 88–98.

Hagg, W., Hoelzle, M., Wagner, S., Mayr, E., & Klose, Z. (2013). Glacier and runoff changes in the Rukhk catchment, upper Amu-Darya basin until 2050. *Global and Planetary Change, 110*, 62–73.

Huang, Z., Hejazi, M., Li, X., Tang, Q., Vernon, C., Leng, G., … Wada, Y. (2018). Reconstruction of global gridded monthly sectoral water withdrawals for 1971–2010 and analysis of their spatiotemporal patterns. *Hydrology and Earth System Sciences, 22*(4), 2117–2133.

Ibragimov, N., Evett, S. R., Esanbekov, Y., Kamilov, B., Mirzaev, L., & Lamers, J. P. A. (2007). Water use efficiency of irrigated cotton in Uzbekistan under drip and furrow irrigation. *Agricultural Water Management, 90*(1–2), 112–120.

Khan, M. S., Liaqat, U. W., Baik, J., & Choi, M. (2018). Stand-alone uncertainty characterization of GLEAM, GLDAS and MOD16 evapotranspiration products using an extended triple collocation approach. *Agricultural and Forest Meteorology, 252*, 256–268.

Lee, S. O., & Jung, Y. (2018). Efficiency of water use and its implications for a water food nexus in the Aral Sea Basin. *Agricultural Water Management, 207*, 80–90.

Li, Z., Fang, G., Chen, Y., Duan, W., & Mukanov, Y. (2020). Agricultural water demands in Central Asia under 1.5 °C and 2.0 °C global warming. *Agricultural Water Management, 231*, 106020.

Lu, X., & Zhuang, Q. (2010). Evaluating evapotranspiration and water-use efficiency of terrestrial ecosystems in the conterminous United States using MODIS and AmeriFlux data. *Remote Sensing of Environment, 114*(9), 1924–1939.
Micklin, P. (2016). The future Aral Sea: Hope and despair. *Environmental Earth Sciences*, 75(9), 844.
Mu, Q., Zhao, M., & Running, S. W. (2011). Improvements to a MODIS global terrestrial evapotranspiration algorithm. *Remote Sensing of Environment*, 115(8), 1781–1800.
Mu, Q., Zhao, M., & Running, S. W. (2013). MODIS global terrestrial evapotranspiration (ET) product (NASA MOD16A2/A3). *Algorithm theoretical basis document, collection 5*. Missoula, MT 59812: Numerical terradynamic simulation Group, College of forestry and conservation, The University of Montana.
Running, S., Mu, Q., & Zhao, M. (2015). MOD17A2H MODIS/terra gross primary productivity 8-day L4 global 500m SIN grid V006. Reston, VA: NASA EOSDIS Land Processes DAAC.
Tang, X., Li, H., Desai, A. R., Nagy, Z., Luo, J., Kolb, T. E., … Ammann, C. (2014). How is water-use efficiency of terrestrial ecosystems distributed and changing on Earth? *Scientific Reports*, 4, 7483.
Turner, D., Ritts, W., Cohen, W., Gower, S. T., Running, S. W., Zhao, M., & Ahl, D. E. (2006). Evaluation of MODIS NPP and GPP products across multiple biomes. *Remote Sensing of Environment*, 102, 282–292.
Unger-Shayesteh, K., Vorogushyn, S., Farinotti, D., Gafurov, A., Duethmann, D., Mandychev, A., & Merz, B. (2013). What do we know about past changes in the water cycle of Central Asian headwaters? A review. *Global and Planetary Change*, 110, 4–25.
Wang, H., Li, X., Ma, M., & Geng, L. (2019). Improving estimation of gross primary production in dryland ecosystems by a model-data fusion approach. *Remote Sensing*, 11, 225.
Wang, L., Zhu, H., Lin, A., Zou, L., Qin, W., & Du, Q. (2017). Evaluation of the latest MODIS GPP products across multiple biomes using global eddy covariance flux data. *Remote Sensing*, 9(5), 418.
Wang, X., Chen, Y., Li, Z., Fang, G., Wang, F., Liu, H. (2020a). The impact of climate change and human activities on the Aral Sea Basin over the past 50 years. *Atmospheric Research*, 245. doi:10.1016/j.atmosres.2020.105125
Wang, X., Chen, Y., Li, Z., Fang, G. and Wang, Y. (2020b). Development and utilization of water resources and assessment of water security in Central Asia. *Agricultural Water Management*, 240, 106297.
Wang, Y., Jing, C., Bai, J., Long-Hui, L. I., Xi, C., & LUO Ge-Ping, A. (2014). Characteristics of water and carbon fluxes during growing season in three typical arid ecosystems in Central Asia. *Chinese Journal of Plant Ecology*, 38(8), 795–808. [In Chinese with English abstract].
Wu, X., Zhou, J., Wang, H., Li, Y., & Zhong, B. (2015). Evaluation of irrigation water use efficiency using remote sensing in the middle reach of the Heihe River, in the semi-arid Northwestern China. *Hydrological Processes*, 29(9), 2243–2257.
Xu, Z., Chau, S. N., Chen, X., Zhang, J., Li, Y., Dietz, T., … Liu, J. (2020). Assessing progress towards sustainable development over space and time. *Nature*, 577(7788), 74–78.
Zeri, M., Hussain, M. Z., Anderson-Teixeira, K., DeLucia, E., & Bernacchi, C. J. (2013). Water use efficiency of perennial and annual bioenergy crops in central Illinois. *Journal of Geophysical Research: Biogeosciences*, 118(2), 581–589.
Zhang, J. Y., Chen, Y. N., Li, Z., Song, J., Fang, G., Li, Y., & Zhang, Q. (2019). Study on the utilization efficiency of land and water resources in the Aral Sea Basin, Central Asia. *Sustainable Cities and Society*, 51, 101693.
Zhao, M., Heinisch, F., Nemani, R., & Running, S. W. (2005). Improvements of the MODIS terrestrial gross and net primary production global data set. *Remote Sensing of Environment*, 95(2), 164–176.
Zou, J., Ding, J., Welp, M., Huang, S., & Liu, B. (2020). Assessing the response of ecosystem water use efficiency to drought during and after drought events across Central Asia. *Sensors*, 20(3), 581.