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Ecological Assessment of Terminal Lake Basins in Central Asia under Changing Landscape Patterns

Wei Yan [1], Xiaofei Ma [2,3,4,*], Yuan Liu [5], Kaixuan Qian [6], Xiuyun Yang [6], Jiaxin Li [5] and Yifan Wang [1]

1 School of Geographic Sciences, Xinyang Normal University, Xinyang 464000, China
2 State Key Laboratory of Desert and Oasis Ecology, Xinjiang Institute of Ecology and Geography, Chinese Academy of Sciences, Urumqi 830011, China
3 Research Centre for Ecology and Environment of Central Asia, Chinese Academy of Sciences, Urumqi 830011, China
4 Sino-Belgian Joint Laboratory of Geo-Information, Urumqi 830011, China
5 College of Geography and Remote Sensing Science, Xinjiang University, Urumqi 830046, China
6 Xinjiang Laboratory of Lake Environment and Resources in Arid Zone, Xinjiang Normal University, Urumqi 830054, China
* Correspondence: mxf@ms.xjb.ac.cn

Abstract: Climate change and anthropogenic activities drive the shrinkage of terminal lakes in arid areas to varying degrees. Ecological water conveyance (EWC) projects have emerged globally to restore the ecology of terminal lakes. However, there remains a lack of qualitative evaluation of the benefits of EWC on terminal lakes. This study compared the Taitema Lake Basin with the Aral Sea Basin in Central Asia, representative of terminal lake basins with and without EWC, respectively. The results show that the water area of Taitema Lake increased by 7.23 km^2/year due to EWC (2000–2019), whereas that of the Aral Sea Basin decreased by 98.21% over the entire process of natural evolution (1972–2019). Land use changes before and after the EWC (1990–2019) included an increase and decrease in desert land and water bodies in the Aral Sea Basin, and a decrease and increase in desert land and arable land in the Tarim River Basin, respectively. The normalized difference vegetation index (NDVI) and actual evaporation (ETa) are the main factors influencing the change in the water area of the Aral Sea Basin with the changing environment, while EWC is the main factor influencing the change in the water area of Taitema Lake. The results confirm that EWC is a feasible measure for achieving ecological restoration of a terminal lake watershed in an arid area.

Keywords: Central Asia; inland river; sustainable development; terminal lake; water conveyance

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1. Introduction

Water resources are essential for the survival and development of human societies [1–3]. Precipitation and snowmelt from mountainous areas generally act as the source waters for inland river basins [4,5]. Climate change and anthropogenic activities have been the main drivers of a reduction in global lake numbers by 37% in 2015 compared to pre-industrial levels [6,7]. In China, approximately 243 lakes with areas exceeding 1 km^2 have disappeared over the last 30 years, particularly in arid areas [8,9]. The terminal lake of an inland river is an important component of the mountain–oasis–desert landscape system in arid areas and is extremely sensitive to natural and anthropogenic changes [10–12]. The ecosystem service functions of terminal lakes include water conservation, wind prevention, sand fixation, and the regulation of the local microclimate [13]. However, the large-scale development of irrigated agriculture and the impacts of climate change over the past half-century have resulted in the catastrophic shrinkage of terminal lakes. The shrinkage of terminal lakes exposes large areas of lakebeds and forms a new type of salt-rich desert [14], resulting in extreme deterioration of the surrounding ecological environment [15,16]. In addition, most terminal lakes fall within the tuyere area, and the exposed lake beds experience frequent erosion due to strong zonal winds. These winds result in salt/sandstorms that transport large quantities of salt substances, posing a significant threat to the local environment and human health [17,18]. Ecological water conveyance (EWC) means that a river or basin with relatively abundant water resources, while meeting the sustainable development of its own ecosystem, still has excess water to recharge surrounding or tributary systems, thus allowing the ecosystem of the recharge basin to be restored and ecosystem services to be maximized [10,19]. Ecological protection is the primary aim of EWC projects. Since 2000, the Chinese government has successively invested tens of billions of yuan in arid regions of the inland river basins, including the Tarim, Heihe, and Shiyang River Basins, through the implementation of EWC projects, resulting in surges in the water areas of some terminal lakes [19–21]. However, there has been an increase in uncertainties of the response of terminal lakes in arid regions due to localized changes in climate and intensive anthropogenic activities. The rational and optimal allocation of water resources focuses on solving the balance between agricultural irrigation water and ecological water [21]. In arid areas, priority should be given to the current situation of regional water resources. For regions where water resources are relatively scarce and the ecological environment is deteriorating, priority should be given to ensuring water for the ecological environment and then moderately developing some drought-tolerant crops [22].

Central Asia falls within the Eurasian continent and has had a warming rate of 0.60 °C/decade over the last 30 years, which is significantly higher than the average rate of land surface warming in the global land areas (0.27–0.31 °C/decade) [23]. In addition, the rate of warming in Central Asia is highest in the central regions and gradually decreases from northwest to southeast [24,25]. Climate warming in Central Asia has also accelerated the rate of snow–ice melt, and increased anthropogenic activities have significantly reduced ecosystem services such as soil conservation, windbreaks, and sand fixation [26,27]. Zones with remarkable ecological deterioration and ecological engineering have emerged over the past 20 years. For example, the Aral Sea in Central Asia, a transboundary international river, is subject to constant water disputes between the upstream and downstream countries [28,29]. The resulting segregated water and soil development and utilization among the different countries have resulted in the shrinkage of the Aral Sea and associated deterioration in ecosystem services [26,30]. Taitema Lake, a lake situated at the outlet of the Tarim River Basin in Xinjiang, China, has disappeared in the past due to unreasonable anthropogenic development and utilization, which has resulted in extreme deterioration of the surrounding ecological environment. Subsequently, an EWC project implemented by the Chinese government since 2000 restored the area of Taitema Lake, with the lake becoming the second largest in Xinjiang [31,32]. The increase in the water area of the lake has also improved the ecological environment by reversing land degradation and reducing sandstorms.

Many studies have been conducted on the restoration and reconstruction of terminal lakes. Ecological problems experienced by terminal lakes in the monsoon region include eutrophication and water pollution [33–35]. Although there are also water transfer activities, it is of little significance for reference in arid areas. Typical terminal lakes in arid areas have experienced rapid shrinkage over the past 60 years, with some having completely dried up [36–39]. However, regional climate change and EWC projects have contributed to the replenishment of some lakes, along with improvements in the surrounding ecological environment [40,41]. Basins of terminal lakes show great spatial heterogeneity, and climate change and EWC have increased the uncertainty in the evolution of terminal lakes.

The present study compared the Taitema Lake Basin with the Aral Sea Basin, which is representative of a basin with and without EWC, respectively. By comparing and analyzing the environmental changes before and after EWC in the two basins, the objectives of the present study were to: (1) quantify the spatial–temporal variations in areas of water bodies, vegetation, and land use before and after EWC, (2) identify the main drivers of water level change, and (3) analyze the sustainable development strategy of terminal lakes under the influence of climate change and anthropogenic activities.

2. Materials and Methods

2.1. Study Area

Water resources in Central Asia are more sensitive to the impacts of climate change because the sources of water in river basins in this region are mainly snow–ice melt in mountainous areas [29]. An assessment of water resources in Central Asia by the Global International Waters Assessment Program (GIWA) concluded that 70% of development problems in Central Asia result from water deficits [42]. The Aral Sea Basin and the Tarim River Basin fall within the same latitude and represent two major river basins in Central Asia. The Amu Darya and Syr Darya Rivers are two major rivers in the Aral Sea Basin, which eventually empty into the Aral Sea terminal lake (Figure 1). The Aral Sea was the fourth largest lake globally in the 1960s, with an area of 68,478 km^2 [43,44]. However, the effects of climate change and excessive exploitation and utilization of water resources by anthropogenic activities have resulted in shrinkage of the area of the Aral Sea and a sharp increase in salt content. By the end of the 20th century, the area of the Aral Sea had decreased to 25,256 km^2 [29,44]. Rapid shrinkage of the Aral Sea has been widely regarded as one of the main global environmental disasters of the last century [45]. In contrast, Taitema Lake, the terminal lake originating in the Tarim River Basin, dried up completely in 1968. However, since 2000, with the orderly management of water resources in the upper reaches of the Tarim River, ecological balance in the upper reaches has been met while at the same time transporting some water downstream, allowing the ecology of the lower reaches to recover. The water area of Taitema Lake has also increased, resulting in a 3.4-fold increase in the area of low and medium vegetation cover within the lower reaches [31]. These developments indicate that anthropogenic interventions increase the uncertainty of the evolution of terminal lakes.

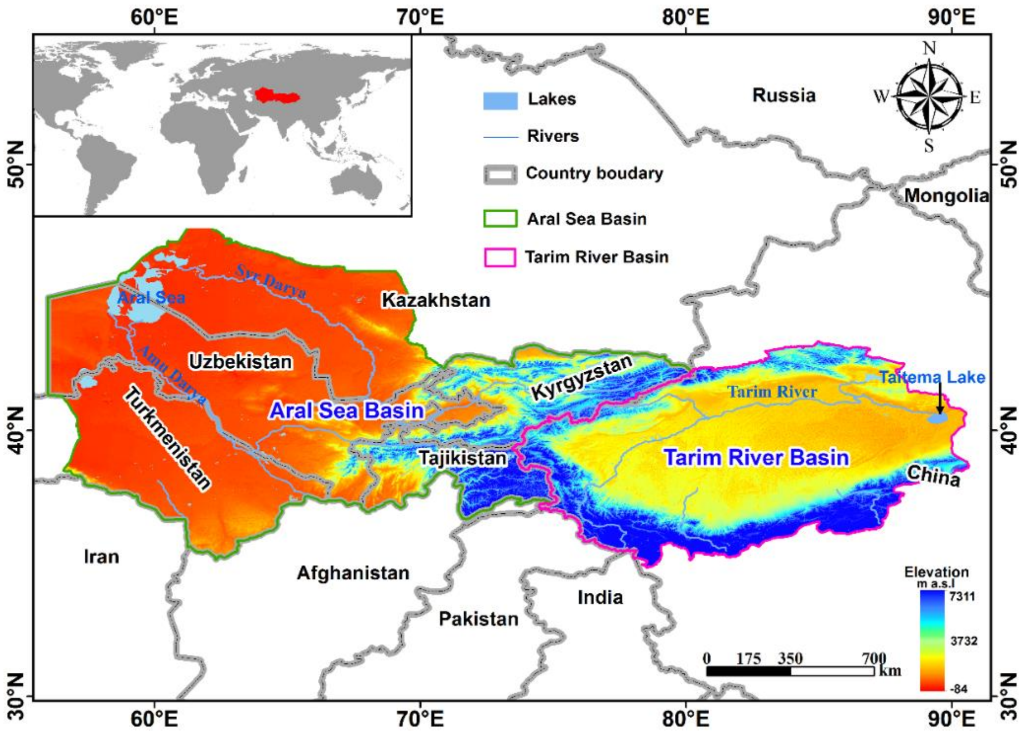

Figure 1. Map showing the locations of the Aral Sea Basin and the Tarim River Basin, Central Asia.

2.2. Data Sources

2.2.1. Meteorological and Hydrologic Data

Although regular meteorological observations in Central Asia have been conducted since the formation of the Soviet Union in the 1920s, the number of observation stations has been limited, with most concentrated in the oasis areas [25,46]. Some observation stations became inoperable after the disintegration of the former Soviet Union, resulting in periods of missing data. Therefore, this study used meteorological data from the Climatic Research Unit (CRU) dataset of the University of East Anglia, United Kingdom (https://crudata.uea.ac.uk/cru/data/hrg/ (accessed on 1 October 2021)). The CRU high-resolution lattice datasets have been widely used globally, and their accuracy and applicability in Central Asia have been verified [47,48]. The present study extracted monthly precipitation and temperature data from the CRU TS V. 4.05 dataset (University of East Anglia, Norwich, UK) covering the Tarim River Basin and the Aral Sea Basin for the period from 1990 to 2019 at a spatial resolution of 0.5°. EWC has been implemented in the Tarim River Basin since 2000. The present study obtained data for the EWC from the Tarim River Basin Administration Bureau for 2000–2019 at an annual time step.

2.2.2. Vegetation and Land Use Data

Vegetation is an important component of terrestrial surface systems [49,50]. The development of satellite remote sensing technology has made it possible to monitor large-scale dynamic changes in vegetation cover [51,52]. Satellite sensors monitoring changes in vegetation cover mainly include the Advanced Very High-Resolution Radiometer (AVHRR), Moderate Resolution Imaging Spectroradiometer (MODIS), Landsat, and SPOT [53,54]. Vegetation indices retrieved from remote sensing data include the normalized difference vegetation index (NDVI), advanced normalized vegetation index (ANVI), enhanced vegetation index (EVI), and ratio vegetation index (RVI) [55–57]. Among them, the NDVI algorithm is simple and has clear physical significance. Moreover, the obvious advantages of NDVI in eliminating the influence of terrain, volcanic aerosols, and other non-vegetation factors have resulted in this index becoming a standard for studying changes in vegetation cover. NDVI is a dimensionless value (-1~1). As the value tends to be closer to 1, the vegetation cover is greater in this area.

The present study used two global datasets, Global Inventory Modelling and Mapping Studies (GIMMS) 3 g NDVI and MODIS NDVI. The GIMMS3g NDVI dataset was obtained from the United States National Oceanic and Atmospheric Administration (NOAA) satellite with spatial and temporal resolutions of 0.0833° and 15 d, respectively, and a time range of 1990 to 2015. The MODIS NDVI dataset was obtained from the US National Aeronautics and Space Administration (NASA) Land Processes Distributed Active Archive Center. The MOD13A2 V6 MODIS NDVI dataset used in the present study was obtained from the MODIS sensor on the Terra satellite and has spatial and temporal resolutions of 1 km and 16 d, respectively, extending from 2016 to 2019. These datasets have been widely used to study long-term changes in the vegetation cover in many regions globally [58–60]. Previous studies have examined the differences between these two datasets [58,61]. The present study used the variance matching method to correct MODIS NDVI data based on GIMMS 3 g data. Finally, NDVI datasets for the Aral Sea Basin and the Tarim River Basin were obtained from 1990 to 2019.

Land use/cover data were obtained from the European Space Agency Climate Change Initiative Land Cover (ESA CCI-LC; https://www.esa-landcover-cci.org (accessed on 1 September 2021)) with a spatial resolution of 300 m and a period from 1992 to 2019. These data have been widely applied in Central Asia [14,62,63]. The present study used 1992 data as the base map, and thematic mapper (TM) images for Central Asia in 1990 were corrected based on visual interpretation. Referring to the classification results of Ma et al. [14] using this data in Central Asia, the study was divided into seven categories: arable land, grassland, forest land, desert land, water bodies, construction land, and others. The verification of land use/cover data through comparison with high-resolution Google Earth images indicated an accuracy exceeding 86%, indicating that manual interpretation of land use/cover data is applicable to Central Asia.

2.3. Methods

2.3.1. Water Area Extraction

The Google Earth Engine (GEE) platform (https://code.earthengine.google.com (accessed on 1 October 2021)) includes historical satellite imagery datasets and geospatial data exceeding 20Pb, including the Landsat dataset [64,65]. The Landsat satellites represent the longest continuous earth observation program globally and the data collected by these satellites are the most widely used form of satellite remote sensing data [66]. Therefore, the present study used Landsat series multi-spectral remote sensing satellite images on the GEE platform as the main data source. Considering the seasonal influences of lakes in the arid region and the effect of more clouds in winter on remote sensing image quality, the months of remote sensing images used in this study are mainly focused on July. Finally, images from the GEE platform were screened to eliminate images with over 20% cloud cover. The GEE platform and normalized difference water index (NDWI) [67] were applied to extract the range of area of the Aral Sea and Taitema Lake.

2.3.2. Actual Evapotranspiration

The present study used the Advection–Aridity (AA) Model based on the complementary correlation theory [68] (Equation (1)) to calculate the actual evapotranspiration (ET_a) in Central Asia (Equation (2)). In this model, the Penman formula (Equation (3)) was used to calculate the potential evapotranspiration [69], and the Priestley–Taylor formula (Equation (4)) was used to calculate the evapotranspiration in a humid environment [70]. The main equations are as follows:

$$ET_a = 2ET_w - ET_p \tag{1}$$

$$ET_a = (2\alpha - 1)\frac{\Delta}{\Delta + \gamma}(R_n - G) - \frac{\Delta}{\Delta + \gamma}E_a \tag{2}$$

$$ET_p = \frac{\Delta(R_n - G)}{\Delta + \gamma} + \frac{\Delta E_a}{\Delta + \gamma} \tag{3}$$

$$ET_w = \alpha\frac{\Delta(R_n - G)}{\Delta + \gamma} \tag{4}$$

In Equations (1)–(4), Δ is the slope of the temperature-saturated vapor pressure curve (KPa/°C), γ is the wet and dry surface constant (KPa/°C), R_n is the net surface radiation, defined as the difference between the net short-wave radiation and the net long-wave radiation (mm/day), and G is the soil heat flux (mm/day). The soil heat flux is negligible in comparison with the net radiation, particularly under sparse surface vegetation. Under a calculation timestep of less than 10 d, G usually approximates 0 [71]. E_a represents the drying force (mm/day). The definitions of the relevant variables in the formula are given by Allen et al. [72]. α represents the Priestley–Taylor empirical coefficient. According to Ma et al. [73] and Su et al. [74], the AA model was used for parameter calibration in the northern sand region of China and the Tarim Basin in Central Asia.

2.3.3. Trend Analysis

The unitary regression trend method can be used to analyze the trend in the variation of a single pixel and to quantify the spatial characteristics of the dynamic changes of all grids over a given period [14]. The present study used this method to evaluate the trend in the spatial variation of environmental variables in the Aral Sea Basin and the Tarim River Basin.

$$\theta_{slope} = \frac{n \times \sum_{i=1}^{n}(i \times P_i) - \sum_{i=1}^{n} i \sum_{i=1}^{n} P_i}{n \times \sum_{i=1}^{n} i^2 - (\sum_{i=1}^{n} P_i)^2} \tag{5}$$

In Equation (5), θ_{slope} is the trend slope, n is the time scale, i represents a certain time node, and P_i represents the environment variable in year i. $\theta_{slope} > 0$, $\theta_{slope} < 0$, and $\theta_{slope} = 0$

indicate an increase, decrease, and no change in the environmental variables during this period.

3. Results

3.1. Spatiotemporal Variation in Water Resources

Figure 2 shows the changes in the water area and EWC of the Aral Sea and Taitema Lake before and after EWC (1972–2019). The results show that there was a linearly decreasing trend in the water area of the Aral Sea before EWC (1972–1999; −1364.25 km^2/year). The rate of decrease slowed after 2000 (−1306.43 km^2/year). Overall, the area of the Aral Sea has decreased by 98.21% over the last 48 years. Currently, submerged parts of the Aral Sea are concentrated in the north, whereas the southern part is dominated by dry riverbeds. Taitema Lake was completely dry before EWC. Since the implementation of EWC in 2000, the annual water delivery to the Tarim River will be 0.18 × 10^8 m^3/year by 2019. Consequently, the area of Taitema Lake has increased by 7.23 km^2/year, mainly in the north.

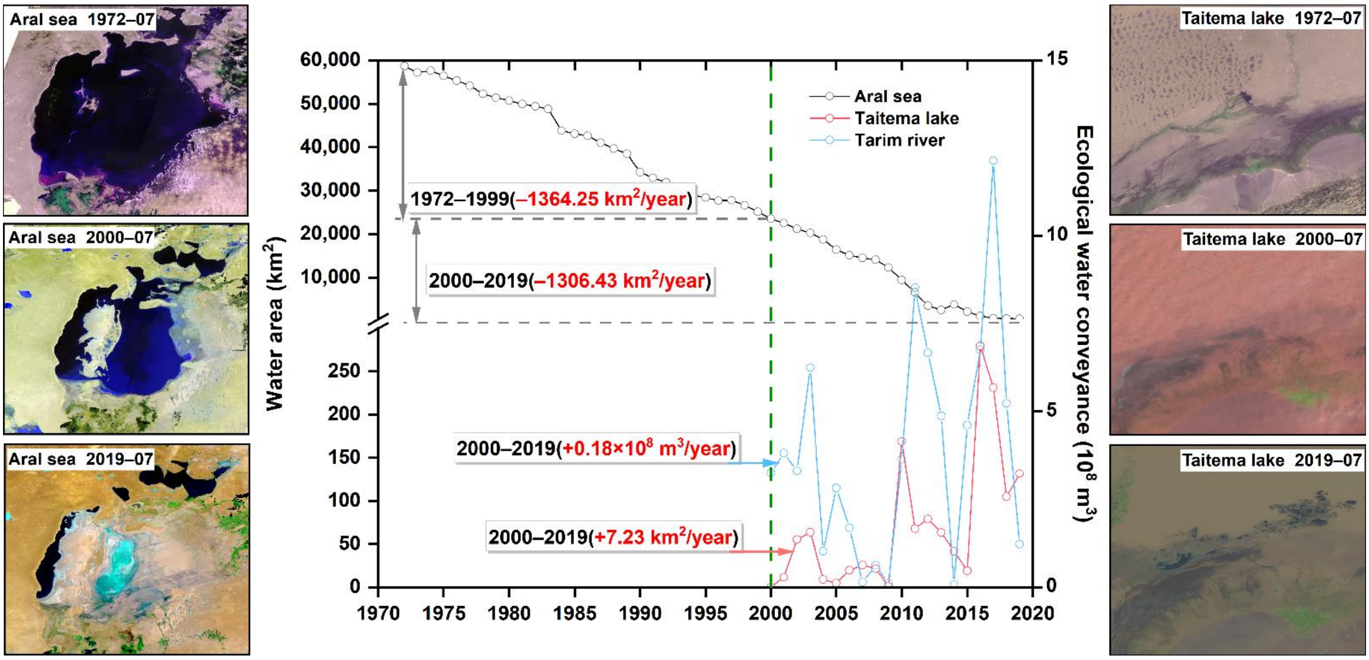

Figure 2. Spatial and temporal variation of water resources in the Aral Sea and Taitema Lake, Central Asia, before and after EWC to the Tarim River.

3.2. Land Use Change

Land use in the Aral Sea Basin and the Tarim River Basin changed significantly before and after EWC (1990–2019) (Figures 3 and 4). Prior to EWC (1990–1999), changes in land use in the Aral Sea Basin included increases in desert land and arable land of 7455 km^2 and 2594 km^2, respectively, whereas there were decreases in the areas of water bodies and grassland of 9484 km^2 and 3351 km^2, respectively. After EWC (2000–2019), there were significant increases in the desert land and construction land of 11,277 km^2 and 5115 km^2, respectively, whereas there was a decrease in the area of water bodies by 22,311 km^2. The increase in land for construction has mainly been influenced by urbanization. The population of the Aral Sea Basin increased by almost 35 million in 2019 compared to 1990 [75]. In contrast, changes in land use in the Tarim River Basin before EWC (1990–1999) were mainly manifested as a decrease in the area of desert land of 4221 km^2 and an increase in the area of arable land of 2939 km^2. After EWC (2000–2019), desert land further decreased by 10,390 km^2, whereas arable land and grassland increased by 5822 km^2 and 2070 km^2, respectively.

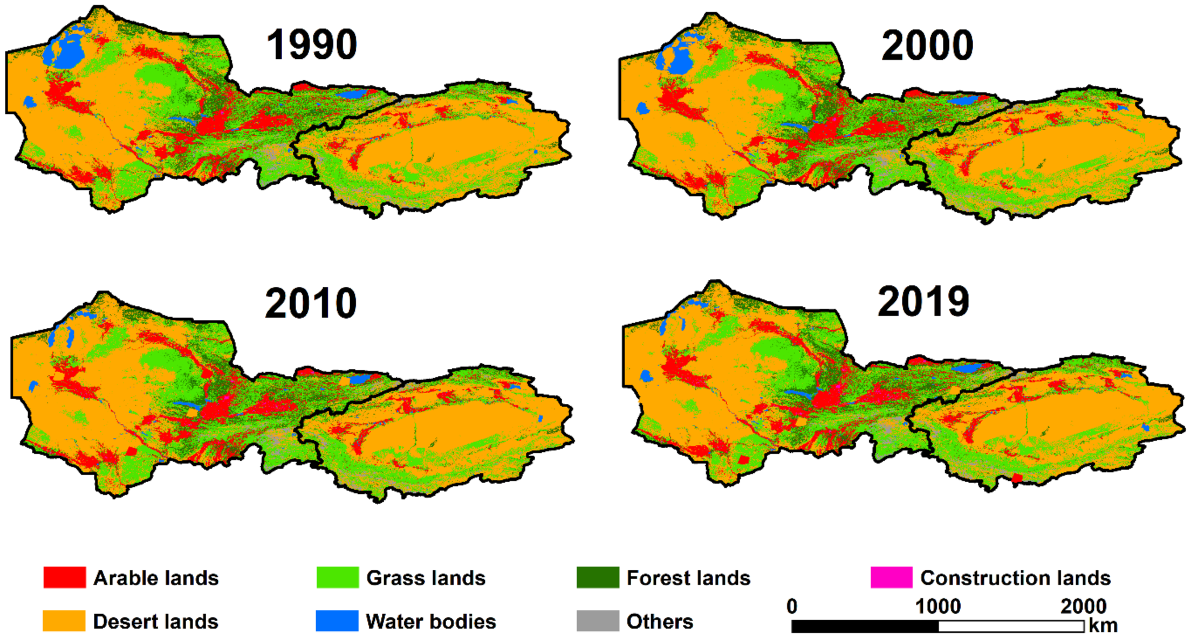

Figure 3. Land use change in the Aral Sea Basin and the Tarim River Basin, Central Asia, before and after EWC.

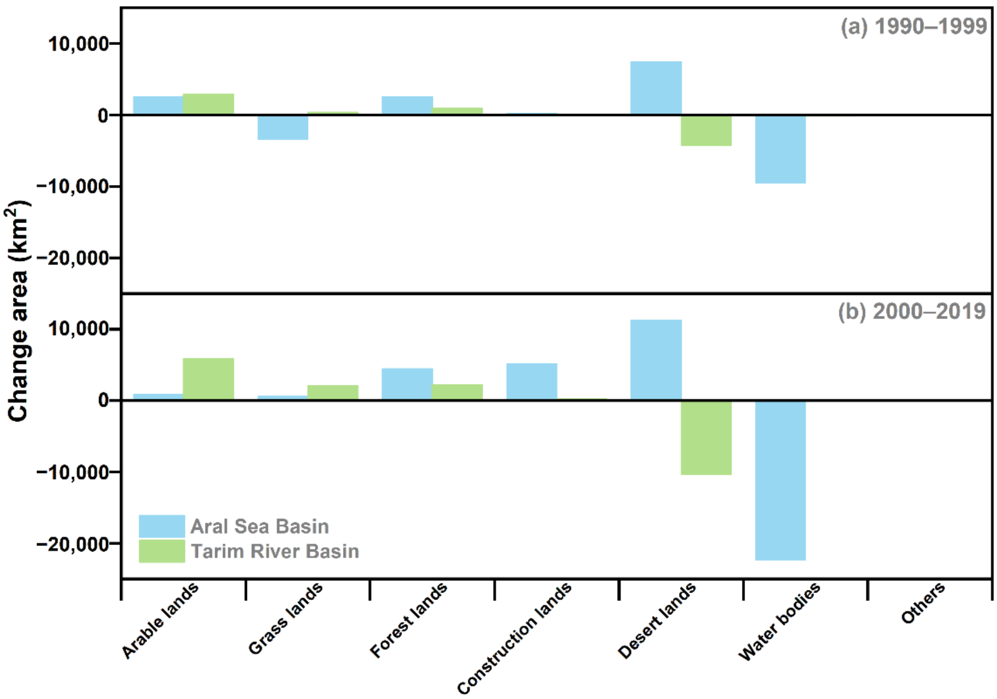

Figure 4. Changes in areas of different land use types before and after EWC in the Aral Sea Basin and the Tarim River Basin, Central Asia.

3.3. Variations in Vegetation

The NDVIs of the Aral Sea Basin and the Tarim River Basin after EWC were significantly different from those before EWC (1990–2019; Figure 5). The area showing an increase in NDVI in the Aral Sea Basin before the EWC (1990–1999) accounted for 63.1% of the entire basin, with increases mainly distributed in the upper reaches of the Amu Darya and the Syr Darya Rivers. There was a downward trend in the overall NDVI of the Aral Sea Basin after EWC (2000–2019), with areas showing a decrease in the NDVI, accounting for 51.8%

of the entire basin and mainly concentrated in the upper reaches of the Amu Darya and Syr Darya Rivers.

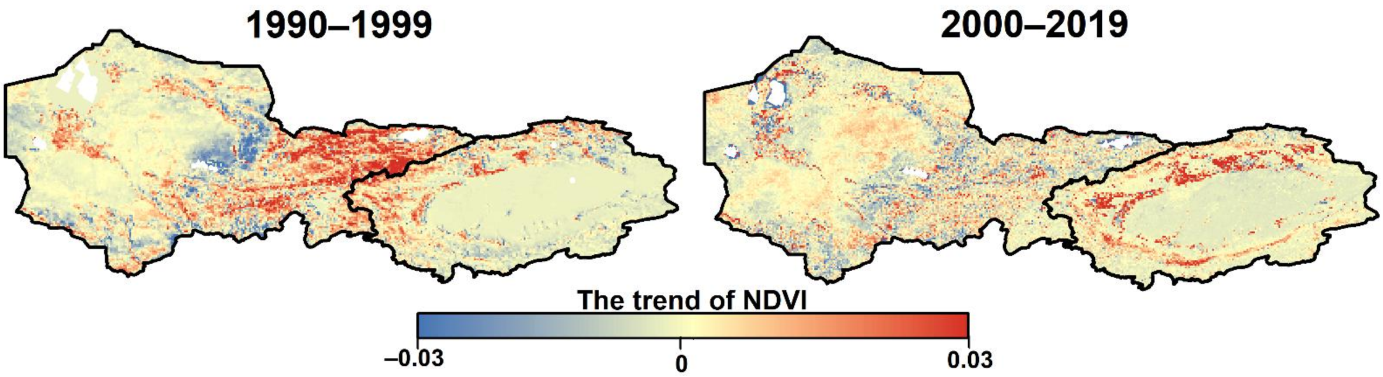

Figure 5. Spatial variation in the NDVI in the Aral Sea Basin and the Tarim River Basin, Central Asia, before and after EWC.

Although there were increases in the NDVI in the Tarim River Basin before and after EWC (1990–2019), a more significant increase occurred after EWC (2000–2019). The areas showing an increase in the NDVI accounted for 72.1% of the entire basin and were mainly distributed in the oasis regions (Table 1).

Table 1. Changes in the NDVI in the Aral Sea Basin and the Tarim River Basin, Central Asia, over different periods before and after EWC.

Basins	1990	1999	2000	2019	A_i:A_a	
					1990–1999	2000–2019
Aral Sea Basin	0.12	0.13	0.13	0.08	63.1%	48.2%
Tarim River Basin	0.08	0.12	0.13	0.16	51.6%	72.1%

Note: A_i:A_a represents the area in which there was an increase in the NDVI as a percentage of the entire basin.

3.4. Variations in ETa

The analysis of the *ETa* of the Aral Sea Basin and the Tarim River Basin (Figure S1; Table 2) shows an increasing trend in the Aral Sea Basin before (1990–1999) and after (2000–2019) EWC, evident in 99.54% and 100% of the basin, respectively. Prior to EWC (1990–1999), regions in the Tarim River Basin showing an increasing trend in the *ETa* accounted for 94.6% of the Tarim River Basin, whereas regions showing a decreasing trend were mainly distributed in the center of the Taklimakan desert. After EWC (2000–2019), the *ETa* increased in 98.9% of the Tarim River Basin. The *ETa* of the two basins shows a decreasing spatial pattern from east to west.

Table 2. Changes in the actual evaporation (ETa, unit: mm) in the Aral Sea Basin and the Tarim River Basin, Central Asia, over different periods before and after EWC.

Basins	1990	1999	2000	2019	A_i:A_a	
					1990–1999	2000–2019
Aral Sea Basin	426	443	454	471	99.4%	100%
Tarim River Basin	387	416	423	447	94.6%	98.9%

Note: A_i:A_a represents the area in which there was an increase in the ETa as a percentage of the entire basin.

4. Discussion

4.1. Key Factors Affecting Changes in Water Resources

The impacts of global warming have resulted in significant increases in the temperatures of the Tarim River Basin and the Aral Sea Basin in Central Asia [25,26,76,77]. A study by Chen et al. [78] determined that the warming of this region has exceeded the average of the Northern Hemisphere by a factor of two over the past century. Climate change affects regional water resources, and the water resources in the Aral Sea Basin and the Tarim River Basin are more sensitive to climate change since they are mainly supplied by snow–ice melt of headwater mountain areas [28,30,79]. An analysis of the changes in the temperature and precipitation in the Aral Sea Basin and the Tarim River Basin before and after EWC (Figure S2) shows that although there were increases in the temperature and precipitation after EWC, the range of warming in the Tarim River Basin significantly exceeded that in the Aral Sea Basin. This phenomenon can possibly be attributed to the EWC in the Tarim River Basin, changes in the regional microclimate, and an increase in the inland water vapor cycle.

Many factors regulate changes in the water resources of a basin. A study of the changes in the water resources of the Ebinur Lake Basin by Wang et al. [80] showed that an increase in the regional precipitation was the main driver of the increase in water area over the last decade. A study of the changes in water resources in many lakes on the Qinghai–Tibet Plateau by Zhang et al. [81] showed multiple sources of water supply, including precipitation, snow and glacier melting, and permafrost degradation, drove the increase in lake water resources on the Qinghai–Tibet Plateau. The present study found that the NDVI and ETa were the main factors affecting changes in the water area in the Aral Sea Basin, whereas that in the Tarim River Basin was EWC (Figure 6). EWC not only increased the NDVI in the Tarim River Basin but also led to an increase in biomass, such as the NPP, in the basin. Chen et al. [82] found that EWC increased the NPP by 7.6 g C m^{-2} in the Tarim River Basin. The increases in the NDVI and ETa in the Tarim River Basin are, on the one hand, due to the recovery of vegetation after EWC, and on the other hand, due to the rational and optimal allocation of agricultural water in the region and the reduction of unreasonable upstream irrigation diversions [83].

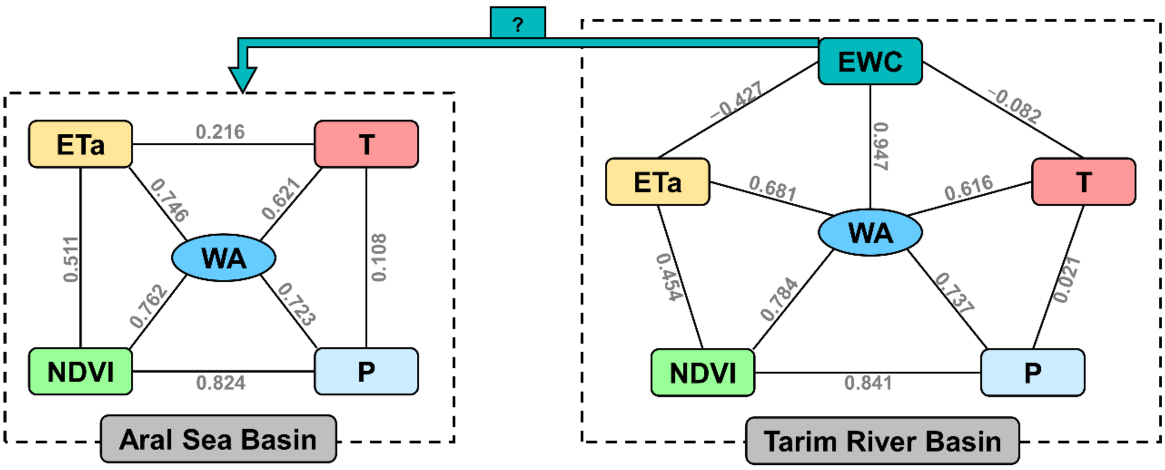

Figure 6. Relationships between the main factors driving changes in water area (WA) in the Aral Sea Basin and the Tarim River Basin, Central Asia. ETa represents the actual evapotranspiration; T represents the temperature; P represents the precipitation; NDVI represents the normalized difference vegetation index; EWC represents the ecological water conveyance. "?" represents whether the EWC project in the Tarim River Basin can be applied to the Aral Sea basin. The grey numbers on each line indicate the correlation (Pearson correlation coefficient) between the factors at either end of the line [84]. The closer this value converges to 1, the more likely it is that the two are significantly positively correlated.

4.2. Trade-Off and Synergy Relationships of the Riparian Ecosystem in Arid Regions under Climate Change

An assessment of water resources in Central Asia by the GIWA Program concluded that 70% of the development problems in the region are initiated due to water deficits, and mainly changes in river runoff [42,85]. Although there are increasing trends in the temperature and precipitation in Central Asia [86,87], there are corresponding increasing and decreasing trends in the ETa [88,89] and soil water content [90,91], respectively. Consequently, there has been no change in the degree of drought in Central Asia [92,93]. Most of the rivers in Central Asia originate in the Tianshan Mountains, among which the Syr Darya, Amu Darya, and Tarim Rivers are the most typical (Figure 7).

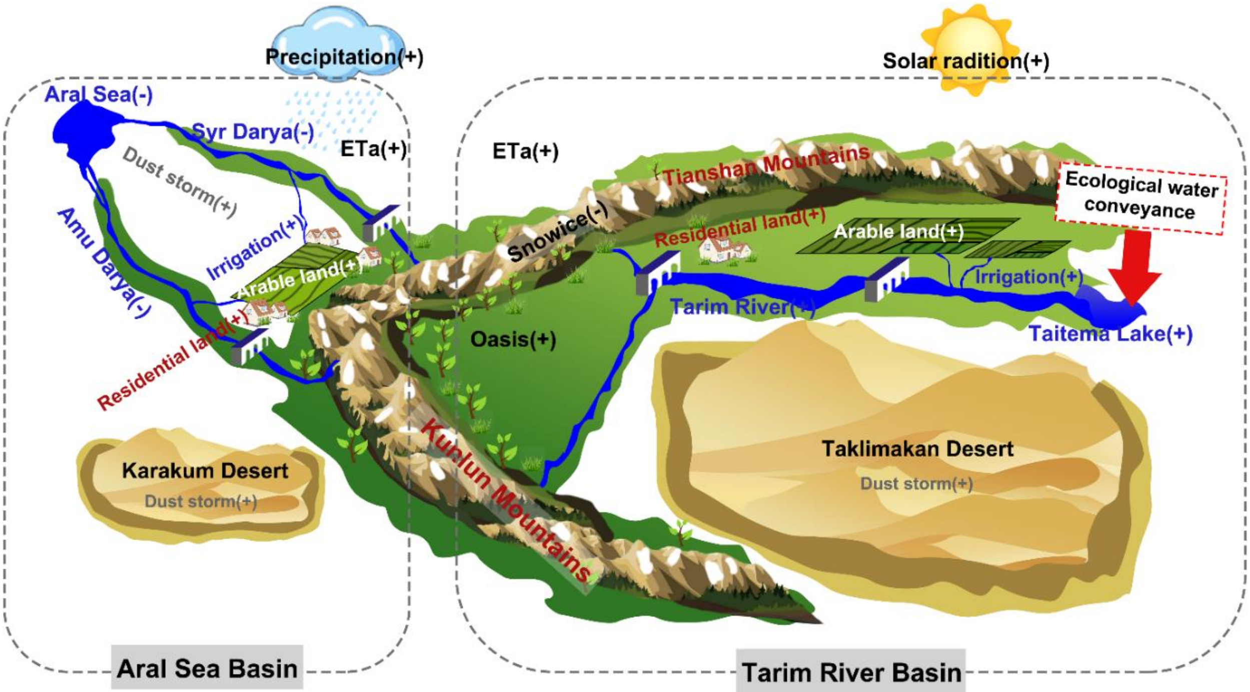

Figure 7. Schematic diagram summarizing the response of water resources to climate change in the Aral Sea Basin and the Tarim River Basin, Central Asia. For each factor impacting the water resource, the corresponding symbols "+"and "−" in brackets represent an increasing trend and a decreasing trend, respectively, in response to climate change.

The source of water resources of the Aral Sea Basin and the Tarim River Basin is mainly snow–ice melt in the headwater mountain areas. These water resources are consumed in the lower reaches through agricultural irrigation and evaporation [79,94]. Water shows an uneven spatial distribution in Central Asia, with the number of surface water resources in Kyrgyzstan and Tajikistan comprising over 70% of total water in Central Asia, whereas the consumption of these regions accounts for less than 10% of the total consumption [29,95,96]. In contrast, although the surface water resources of Kazakhstan, Uzbekistan, and Turkmenistan account for ~30% of the total water resources of Central Asia, the water consumption of these regions accounts for over 85% of the total consumption. Chen et al. [97] concluded that "The water crisis in Central Asia is not a quantitative crisis, but a distribution crisis; the problem is not water shortage, but water management". Although water in Central Asia is plentiful, it remains poorly managed. While relevant countries and international organizations have made considerable efforts to coordinate the management of the Aral Sea Basin, problems and inter-country conflicts persist. The Tarim River Basin and the Aral Sea Basin are both important components of the arid area of Central Asia and have similar water cycles, hydrologic environments, and water resource utilization. After nearly 20 years of development, China has accumulated rich experience in the development, utilization, and management of water resources in arid areas, of which EWC is the most typical example [12,98].

China originally implemented EWC to improve the ecological environment of the terminal lakes in arid areas, which have experienced deterioration due to climate change and anthropogenic activities [31,99,100]. Long-term shrinkage in the areas of terminal lakes can be attributed to climate change [101,102]. Therefore, restoring the area of Lop Nur and other lakes to historical levels is neither practical nor economical, and the levels of these lakes can only be restored to levels of the modern area [103,104]. Schemes for the delivery of water to terminal lakes have become increasingly common and feature prominently in the life cycle of a terminal lake [37]. Therefore, the restoration of terminal lakes through EWC is a new stage of artificial intervention and reconstruction, which needs to be understood from the perspective of historical evolution.

The environmental challenge of lake restoration and reconstruction in global arid areas is particularly prominent in the Aral Sea Basin in Central Asia and fairly typical of other vast lakes in arid areas of China. The restoration of the Aral Sea involves several countries and mainly involves cross-border cooperation in water management and some engineering measures [105]. For example, as a water conservation measure, Kazakhstan constructed dams between the Large and Small Aral Seas [30] to prevent the flow of water from the Small Aral Sea to the Large Aral Sea [106]. Relevant strategies and technologies for EWC in the Tarim River can be used as a reference for the sustainable development of water in the Aral Sea Basin.

5. Conclusions

The present study adopted the Taitema Lake Basin and the Aral Sea Basin as representative of terminal lake basins in Central Asia with and without EWC, respectively. The EWC implemented in the Taitema Lake Basin was proportional to the water area of Taitema Lake. The area of Taitema Lake increased by 7.23 km^2/year due to EWC (2000–2019), whereas the area of the Aral Sea Basin decreased by 98.21% throughout the natural evolution process (1972–2019). The decrease in the area of the Aral Sea was mainly due to the expansion of farming and land desertification. Although EWC significantly increased the NDVI and ETa in the Aral Sea Basin and the Taitema Lake Basin, they were the main factors affecting changes in the area of the Aral Sea, whereas EWC was the main factor affecting the change in the water area of Taitema Lake.

Ecological restoration of the Aral Sea involves the cooperation of several countries for water resource management. However, the strategies and technologies utilized for EWC in the Tarim River can be used for the sustainable development of the Aral Sea Basin. Arid zone lakes are currently facing a number of environmental problems as a result of global warming, most notably in the Aral Sea Basin. However, the EWC is expected to become a spark initiative for the sustainable development in inland lake basins.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/rs14194842/s1, Figure S1: Spatial variation in actual evaporation (*ETa*) in the Aral Sea Basin and the Tarim River Basin, Central Asia, before and after ecological water conveyance; Figure S2: Spatial variation in precipitation and temperature in the Aral Sea Basin and the Tarim River Basin, Central Asia, before and after ecological water conveyance.

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