Analysis for spatial-temporal matching pattern between water and land resources in Central Asia

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ABSTRACT

Central Asia, the pioneering place of the 'Belt and Road', is under the threat of prominent water issues. Based on the Gini coefficient model and the matching index, the amount of the total renewable water resources and the cultivated land area were introduced to evaluate the matching pattern between the water and land resources in Central Asia. The water problem of Kazakhstan, being the most prominent, shows low water resources per unit area with the highest reclamation rate. The matching degree for the upstream countries of the Aral Sea (Kyrgyzstan, Tajikistan) was better than those of the downstream countries (Turkmenistan, Uzbekistan, Kazakhstan). The Gini coefficient in Central Asia was 0.32, smaller than that of the global average value (0.59). The overall water available for use and the matching cultivated land resources was reasonable. Large differences exist in the matching degree in water distribution and utilization among Central Asian countries. The matching index of water and land resources in Central Asia was 1.25, similar to the matching degree estimated from the Gini coefficient model. Moreover, rational measures are suggested to alleviate the issue of water and land resources matching in Central Asia.

Key words | ArcGIS, spatial and temporal pattern, water and land resources matching, water distribution and utilization

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HIGHLIGHTS

- The Gini coefficient model is to evaluate the overall level of matching degree.
- The matching index model is introduced for evaluating the spatial matching pattern.
- The matching situation for the upstream countries of the Aral Sea was better than those of the downstream countries.
- Two models perform similarly in matching pattern.
- The matching index of water and land resources in Central Asia was 1.25.

INTRODUCTION

Central Asia, located in the hinterland of the Eurasian continent, lacks water resources (Gafurov *et al.* 2012). It is one of the regions threatened by serious water problems in the world (Unger-Shayesteh *et al.* 2013). The economic benefits of water use in Central Asia are lower than those in other areas of Asia (Lee & Jung 2018). Although the total amount of water resources is seemingly large in this region, in fact, only 24.4% is available for use by humans (Yang *et al.* 2017). On top of that, multiple transboundary rivers exist in Central Asia (Zhupankhan *et al.* 2018).

However, the mismatched spatial distributions of water and land resources, along with the intense human activities (e.g., overexploitation of water resources), has ultimately led to the serious water crisis in Central Asia's river basins. This is the main reason for ongoing water conflicts in the region's transboundary rivers and the ecological disaster of the Aral Sea (Chen *et al.* 2018).

Kyrgyzstan and Tajikistan, located in the upstream of the Aral Sea Basin, have the most abundant water resources and are called the 'water towers' of Central Asian countries. However, due to insufficient water conservancy engineering measures, water resources have flowed into downstream countries, so the amount of available water resources in upstream countries is limited. Meanwhile, the downstream countries of the Aral Sea Basin (Kazakhstan, Turkmenistan, and Uzbekistan) enjoy more available water resources, which flow from upstream countries, than their actual domestic water storage (Deng *et al.* 2010). Owing to the limited water storage, the downstream countries are also water-deficient, especially the oil-rich Turkmenistan, which has the saying that 'water is more expensive than oil'.

In the former Soviet Union era, the upstream countries focused on the construction of water conservancy facilities, providing downstream countries with water resources and power resources such as farmland irrigation water, while downstream countries provided more cultivated land and agricultural products for the upstream (Jalilov *et al.* 2016). Since the independence of Central Asian countries, a host of international projects has been launched to achieve sustainable water management, but only a few have been implemented (Abdullaev *et al.* 2009). Uncompensated water use patterns for downstream countries have caused dissatisfaction in upstream countries. The issue of 'energy-water-irrigation' has been plaguing relations between Central Asian countries (Bernauer & Siegfried 2012). Water and land resources, as the basic materials for production and life, are the basis for ensuring national food security (Zhang *et al.* 2019a). For the five Central Asian countries dominated by irrigated agriculture, the shortage of water and land resources has delayed the process of agricultural modernization (Riquelme & Ramos 2005). Generally speaking, the mismatching between the formation area and consumption area of water resources will lead to water

conflicts. The correct evaluation of the formation and consumption of water resources and its spatial matching with land resources is critical to alleviating water problems (Yang *et al.* 2019). Most of the current state-of-the-art studies have focused on the water problems in Central Asia from the aspects of the state of water resources, the water cycle processes, the transboundary river management, and so on (Yang *et al.* 2017). Although previous studies exist for quantitative analysis, they mainly focus on the impact of climate change on the water cycle and the water environment of the basin (Zhu *et al.* 2015). However, there is a lack of study on the matching patterns between water and land resources. Therefore, a quantitative study on spatial distribution difference and the matching pattern change of water and land resources is the basis of a spatial optimal allocation of regional water resources, offering important guidance for efficient utilization of water and land resources in Central Asia.

Spatial-temporal dynamics of water and land resources matching have attracted many researchers' attention. Most researchers have studied the overall matching of water and land resources in the region on the macro-scale of time and space. Liu *et al.* (2006) constructed the matching analysis model of agricultural water and land resources using the total water resources as a parameter and evaluated the matching pattern of agricultural water and land resources in Northeast China. Liu *et al.* (2018) established the Gini coefficient model for agricultural water and land resources allocation and the model for measuring the matching index of the broadly defined agricultural water resources and land resources (MIBAWRLR) to assess the matching degree of the agricultural water and land of the Jiansanjiang Administration and 15 farms in Heilongjiang Province, China. Based on the water and land resources and agricultural output value, Huang *et al.* (2015) used the data envelopment analysis (DEA) model to analyze the situation of water and land resources in Sichuan Province, China. Only a few researchers analyzed the equilibrium state of supply and demand for agricultural land and water resources at the micro-scale. Zhang *et al.* (2019b) constructed a water and land resources matching index calculation model in micro-scale and studied the temporal and spatial dynamics of crop water and land resource matching in the Naoli River Basin, China.

The matching of water and land resources can be calculated from three aspects: calculating the matching index of water and land resources with the total water resources volume per hectare as the index; evaluating the overall matching situation of water and land resource in the region by the Gini coefficient model, based on DEA to analyze the matching characteristics of water and land resources. Although these models are widely used to study the dynamics of regional water and land resources matching, each model has its shortcomings. For the DEA model, the water and land resources are used as the input indicators and the agricultural output as the output index to study the matching degree of water and land resources (Huang *et al.* 2015). However, multiple factors have been found to affect agricultural output value: the amount of agricultural equipment, labor force, water and land resources, etc. Therefore, the results of the DEA model are not satisfactory when only water resources and land resources are taken as research variables. For the Gini coefficient model, different division degrees of units in the region can yield different results. Meanwhile, it can only reflect the overall matching situation of water and land resources in the study area and the relative matching of each unit in the region. For the matching index model, although it reveals the overall matching status of water and land resources in the region, the spatial and temporal distribution and dynamic characteristics of water and land resources matching at the micro-scale are still unclear. At the same time, the model does not take into account the differences in the use of water resources between different types of cultivated land use. However, this model can make up for the errors caused by the division of the unit based on the Gini coefficient, reflect the relative space–time ratio of water and land resources matching. To achieve comprehensive results, we use the Gini coefficient model and the matching index model to analyze the matching situation of water and land resources in Central Asia.

Due to the complexity of transboundary water resources in Central Asia, this paper takes the five countries of Central Asia as the basic unit, then uses total renewable water resource and total water withdrawal as the water resource parameters, and the cultivated area as the cultivated land resource parameter to study the spatial–temporal matching relationship of water and land resources in five Central Asian countries.

MATERIALS AND METHODS

Description of study area

Central Asia refers to the eastern part of the Caspian Sea, south of Western Siberia, north of Afghanistan and Central Asia region to the west of Xinjiang, including Kazakhstan, Uzbekistan, Kyrgyzstan, Tajikistan, and Turkmenistan ($56°34'E–87°19'E$, $35°08'N–55°26'N$). With a total area of nearly 4.00×10^8 hm^2 (excluding coastal waters) and a total population of about 7.08×10^7 in 2017, Central Asia is one of the most sparsely populated areas in the world today. The total renewable water resources in this area are 2.28×10^{11} m^3 and the cultivated area is 3.84×10^7 hm^2. The rivers in Central Asia are mostly inland rivers and lakes, mainly including the Amu Darya, the Syr River, the Chu River, the Aral Sea, and so on (Figure 1). Its terrain is high in the east and low in the west, dominated by plains and hills. The total area of drylands is 5.17×10^6 km^2 (above 80% of the global total temperate desert area) in Central Asia, belonging to the temperate desert climate and grassland continental climate (Li *et al.* 2017). The vegetation is mainly grassland and desert. In most areas, the climate is dry with strong evaporation (Yao *et al.* 2019). The annual precipitation is below 300 mm, and the annual precipitation in the desert near the Aral Sea and Turkmenistan is only 75–100 mm. The territory area of the five Central Asian countries varies greatly, with Kazakhstan's territory being vast, twice the total area of the other four countries. However, although Uzbekistan has a total area of only one-sixth of Kazakhstan, its population is nearly 40% greater than that of Kazakhstan.

Data sources

Since the data of water and land resources in Central Asia are not continuous, this paper uses the data of 1992, 1997, 2002, 2007, 2012, and 2016 from the Food and Agriculture Organization of the United Nations (FAO 2016a). The cultivated area is used as the parameter of cultivated land resources, including arable land and permanent crops. For water resources, the amount of agricultural water, total water withdrawal, and renewable water resources are used. The renewable water resource includes the amount
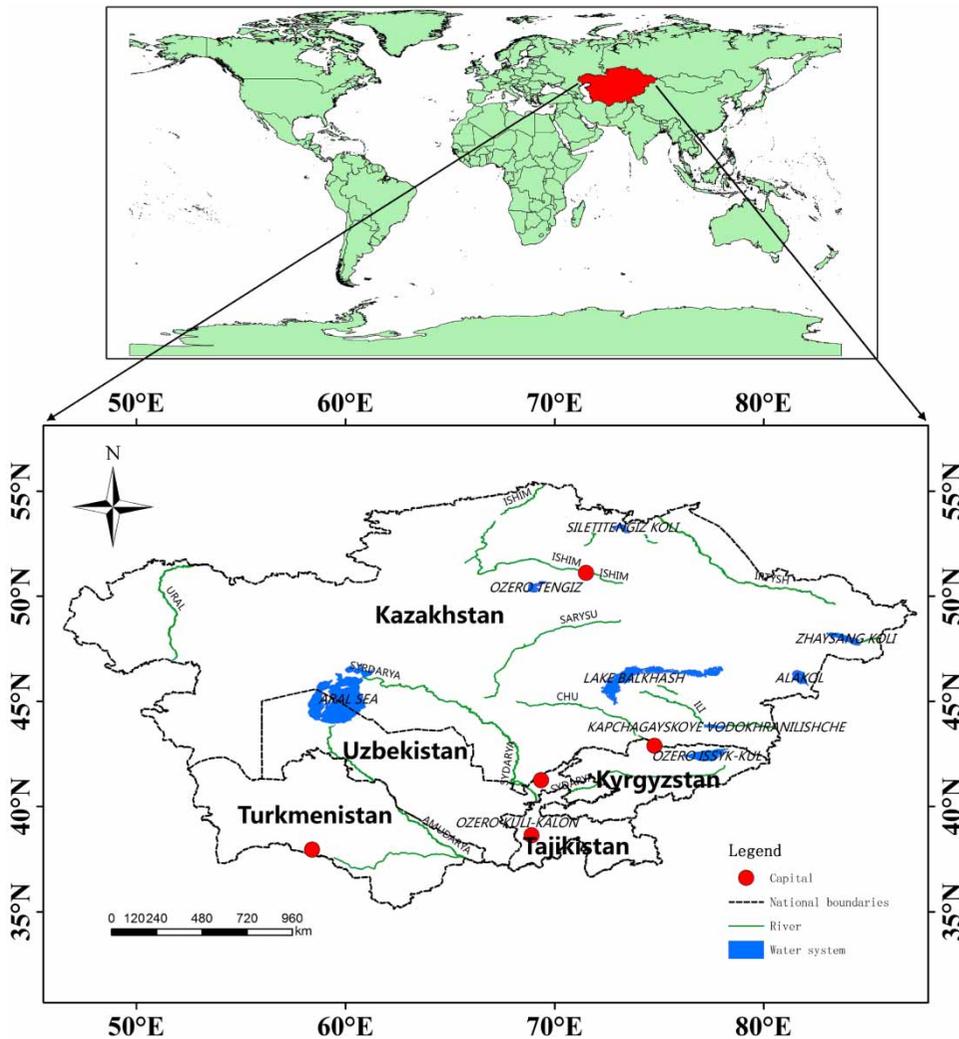
Figure 1 | Research site map of Central Asia.

of surface water and groundwater available in the country. The land cover types are obtained from the global land cover data product with a resolution of 500 m (MCD12Q1 data set) of the Land Process Distributed Active Archive Center (LPDAAC 2015). The area of cropland, grassland, and forest land are collected by the FAO (FAO 2016b).

Theory of water and land resource matching

Matching index model of water and land resources

1. Basic concept: The matching index of water and land resources is expressed by the total water resources volume per hectare. It is a quantitative relationship that reflects the spatial and temporal distribution of water resources and cultivated land resources available for agricultural production in a specific region. It focuses on regional water resources and cultivated land, and coordination and suitability of regional water resources and cultivated land resources in space–time distribution (Liu *et al.* 2006). The higher the matching degree, the better the fundamental conditions of agricultural production are.

2. Calculating model: The matching level of water resources and cultivated areas with five countries in Central Asia are selected as the basic units. The agricultural water withdrawal is determined by the proportion of

agricultural water used to the whole water consumption (agricultural water, industrial water, and municipal water) in Central Asia (Liu *et al.* 2006). The calculation formula is as follows:

$$R_i^{wl} = W_i \alpha_i / L_i, \quad (i = 1, 2, 3, 4, 5) \tag{1}$$

where R_i^{wl} is the matching index of water and land resources of the ith country in Central Asia; W_i is the total renewable water resource of the ith country, $10^8 \, \text{m}^3$; L_i is the area of the cultivated area of the ith country, $10^4 \, \text{hm}^2$; α_i is the proportion of agricultural water in the ith country to the total amount of social and economic water.

The matching index of water and land resources in Central Asia reflects the mean value of the matching index of water and land resources among countries in Central Asia. The calculation formula is as follows:

$$R_j^p = \sum_{i=1}^{n} R_i^{wl} / n \tag{2}$$

where R_j^p is the matching index of water and land resources in area j; R_i^{wl} is the matching index of water and land resources of the ith country in area j; and n is the number of i countries in area j.

Gini coefficient model

The Gini coefficient was proposed by Italian economist Corrado Gini in 1921 when studying income inequality. It has been recognized and applied in many fields. The Gini coefficient (G), also known as the Lorentz coefficient, is determined by calculating the area of the Lorentz curve graph using MATLAB software. First, the Lorentz curve needs to be fitted. Assuming that the area between the actual distribution curve of income and the absolute equal distribution curve is A, and the area between the actual distribution curve of income and the coordinate axis is B, then the Gini coefficient is calculated as follows:

$$G = \frac{A}{A + B} \tag{3}$$

Smaller G value indicates relatively even distribution, while larger G value indicates relatively uneven distribution.

Because the spatial distribution of water resources is diversified, the Gini coefficient is also applicable in the study of the patterns of water and land resource matching. According to the spatial distribution characteristics of water and land resources, the Gini curve construction model for the matching problem of water and land resources in Central Asia is as follows (Liu *et al.* 2018):

1. Take the five countries in Central Asia as the basic calculation units, and calculate the total water resources volume per hectare at each country, then according to the size of this index, the five Central Asian countries are ranked in ascending order.
2. Calculate the percentage of total water resources and cultivated land resources in each unit.
3. The cumulative proportion of water and land resources in each country is calculated following step 1.
4. Draw XY scatter plots, the X coordinate being the cumulative proportion of the cultivated area of each unit, and the Y coordinate is the cumulative proportion of the water resources parameters of each unit, then the Lorenz curve of water and land resources is constructed.
5. Obtain the area of the figure between the Lorentz curve and the slash with an angle of 45°, and an integral between 0 and 1. Then, the Gini coefficient is twice the figure area.

If the G value is between 0 and 1, and the smaller the G value is, the higher the degree of matching. When G = 0, the Lorenz curve completely coincides with the 45° line, and the water and soil resources are completely matched. On the contrary, when G = 1, the matching degree of water and land resources is extremely poor, that is, the cultivated land resources in this area are very rich, and the water resources are in serious shortage.

The internationally accepted model for dividing the Gini coefficient is as follows. For example, G ∈ (0, 0.2) indicates that the degree of matching between water resources and land resources is high (Table 1).

Table 1 | Gini coefficient division standard (Dorfman 1979)

G	Matching results
(0,0.2)	High
[0.2,0.3)	Consistent
[0.3,0.4)	Reasonable
[0.4,0.5)	Inconsistent
[0.5,1)	Poor

RESULTS

The structure and spatial distribution of water and land resources in Central Asia

Composition and utilization of water resources

The total freshwater in the five Central Asian countries is above 1 trillion m³, but the real available water resources are only 206 billion m³, of which, surface water is 187 billion m³ and the non-repetitive groundwater is 19 billion m³ (Table 2). Kazakhstan has the largest water resources, accounting for 36.69% of Central Asia. Turkmenistan has the least (0.68%). Agricultural water consumption accounted for the largest proportion of social and economic water use, with the proportion being 66%, 91%, 93%, 90%, and 94% in Kazakhstan, Tajikistan, Kyrgyzstan, Uzbekistan, and Turkmenistan, respectively (FAO 2016a). The five Central Asian countries have numerous transboundary rivers with large stream flow. Notably, Kazakhstan has a net entry water volume of 34.2 billion m³, followed by Uzbekistan. The net entry water volume of Turkmenistan is much

higher than domestic water resources. Kyrgyzstan and Tajikistan are net exit water resources countries, of which, Kyrgyzstan's net exit water volume accounts for 76% of domestic water resources.

The climate in Central Asia is highly arid with annual precipitation generally below 300 mm. Due to topography and climate, upstream Kyrgyzstan and Tajikistan are the main water sources in Central Asia, with an exit water volume of 76 billion m³, but the main water users are Uzbekistan and Turkmenistan.

Composition and utilization of land resources

The total area of Central Asia is nearly 4.00×10^8 hm². Regarding land types, grassland is the largest proportion (279.5×10^4 km²) and bare areas the second (67.7×10^4 km²). Nearly half of the areas show a natural landscape of desert and semi-desert, and the vegetation coverage in the north and southeast is higher (Figure 2). The highest proportions of cropland, forest land, and grassland are in Uzbekistan (11.21%), Turkmenistan (8.78%), and Kazakhstan (69.44%), respectively (Figure 3). Owing to the disintegration of the former Soviet Union, large-scale cultivation was abandoned in Central Asia. Subsquently, with the independence of Central Asian countries, the social economy gradually recovered, and so did the cultivated areas. Therefore, the cultivated area and crop yield in Central Asia showed a trend of rapid decline first and then a slow rise (Kienzler *et al.* 2012).

The production potential of land resources in Central Asia is huge, but it is constrained by water resources.

Table 2 | Water resources assessment in the five Central Asia countries (FAO 2016a; United Nations 1998)

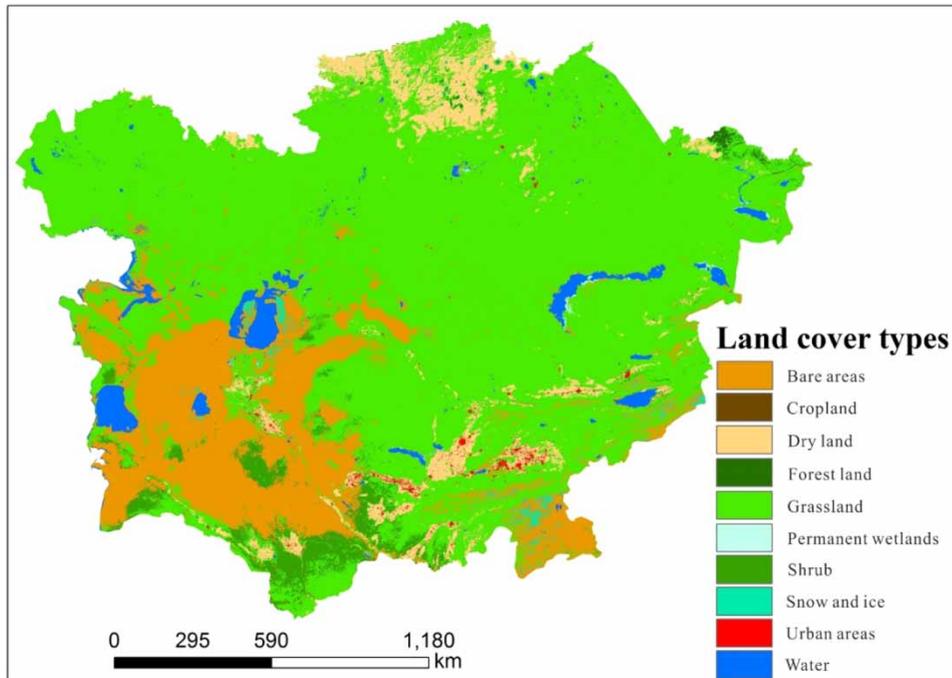| Country	Average precipitation in depth/mm	Surface water/10⁸ m³	Groundwater/10⁸ m³	Overlap between surfaces water and groundwater/10⁸ m³	Water resources/10⁸ m³	Entry-exit water volume/10⁸ m³	Available water resources/10⁸ m³	Water resources per capita/m³
KAZ	250	693	161	100	754	342	1,096	4,142
KGZ	533	441	136	112	465	−259	206	7,692
TJK	691	638	60	30	668	−508	160	7,488
TKM	161	10	4	0	14	233	247	243
UZB	206	95	88	20	163	341	504	511
Sum		1,877	449	262	2,064	149	1,117	4,015.2

Figure 2 │ The types of land cover in Central Asia in 2015.

Meanwhile, a series of ecological and environmental problems in the process of land use seriously restrict the sustainable use of land resources in Central Asia. Effective approaches to these problems are the key to maintaining sustainable development in Central Asia.

Spatial distribution of water and land resources

The water resources per unit area can reflect the richness and shortage of regional water resources, and the reclamation rate can reflect the degree of reclamation of regional cultivated land resources. Five countries in Central Asia are taken as the basic regional units, then the natural breakpoint method of GIS is used to divide the Central Asian region into five grades according to the water resources per unit area and the reclamation rate, producing the spatial distribution pattern of water and land resources (Figure 4).

The spatial distribution of water resources in Central Asia is not uniform and is characterized by a larger amount of water resources in Kazakhstan and a lower amount of water resources in Kyrgyzstan (Figure 4(a)). The distribution of cultivated land in Central Asia is uneven

(Figure 4(b)). Moreover, the spatial distribution of water resources and cultivated land resources in Central Asia is inconsistent (Figure 4). Kazakhstan is the most prominent country, whose water resources per unit area is the lowest, but the reclamation rate is the highest in the region. This spatial dislocation of water and land resources in Central Asia severely limits the increase of regional grain production and sustainable use of resources, which in return, exacerbates the contradiction of water problems in Central Asia.

Matching pattern of water and land resources in Central Asia

Matching degree of water and land resources based on the Gini coefficient

The total renewable water resource is taken as the water resource parameter, and the cultivated land area is used as the land resource parameter. The Gini coefficient of Central Asia in 1992, 1997, 2002, 2007, 2012, and 2016 is shown in Figure 5.

The Gini coefficient showed little variation in 1992, 1997, 2002, 2007, 2012, and 2016, and the matching
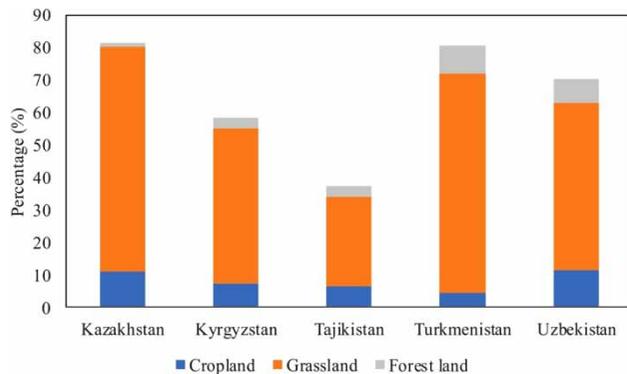
Figure 3 | Proportion of land types in Central Asia in 2016.

situation of water and land resources in Central Asia is relatively reasonable (Figure 5(a)–5(f)). The average Gini coefficient of Central Asia in 1992–2016 was 0.32. According to the internationally recognized Gini coefficient division standard, the degree of matching between water resources and land resources is reasonable. Therefore, the total renewable water resource is not a decisive factor for water problems in Central Asia.

Due to data availability, the total water withdrawal was used as the water resource parameter and the cultivated area as the land resource parameter. Then, the Gini coefficient in Central Asia in 2008 and 2014 were calculated, as shown in Figure 6.

The average Gini coefficient was 0.60 (Figure 6). The total water withdrawal indicates that the matching situation of water and land resources in Central Asia is extremely poor.

Spatial matching pattern of water and land resources based on the matching index model

Since potential errors may exist in the unit division of the Gini coefficient, the matching index model can be used to study the matching situation of water and land resources.

Based on the data of total renewable water resource, cultivated area, and proportion of agricultural water in five Central Asian countries in 1992, 1997, 2002, 2007, 2012, and 2016, the water and land resources matching model is used to obtain the matching index of water and land resources in Central Asian countries, as shown in Table 3.

To visually indicate the difference in the matching situation of water and land resources, the matching index of water and land resources in 2016 is divided into five categories according to the Natural Breaks proposed by Jenks: Poor matching ($0.001 < R \leq 0.242$), Moderate matching ($0.242 < R \leq 0.922$), Relatively good matching ($0.922 < R \leq 1.164$), Good matching ($1.164 < R \leq 1.610$), and Excellent matching ($R > 1.610$). Moreover, the other years are analyzed based on this criterion to form a contrast. Finally, Figures 7 and 8 illustrate the spatial matching pattern of water and land resources in Central Asia.

Combined with the multi-year average of Table 3, the matching index of Kazakhstan is the smallest and the matching index of Tajikistan is the largest, the latter being six times that of the former. By taking the five countries as a whole and calculating the multi-year average matching index of water and land resources from 1992 to 2016, the matching
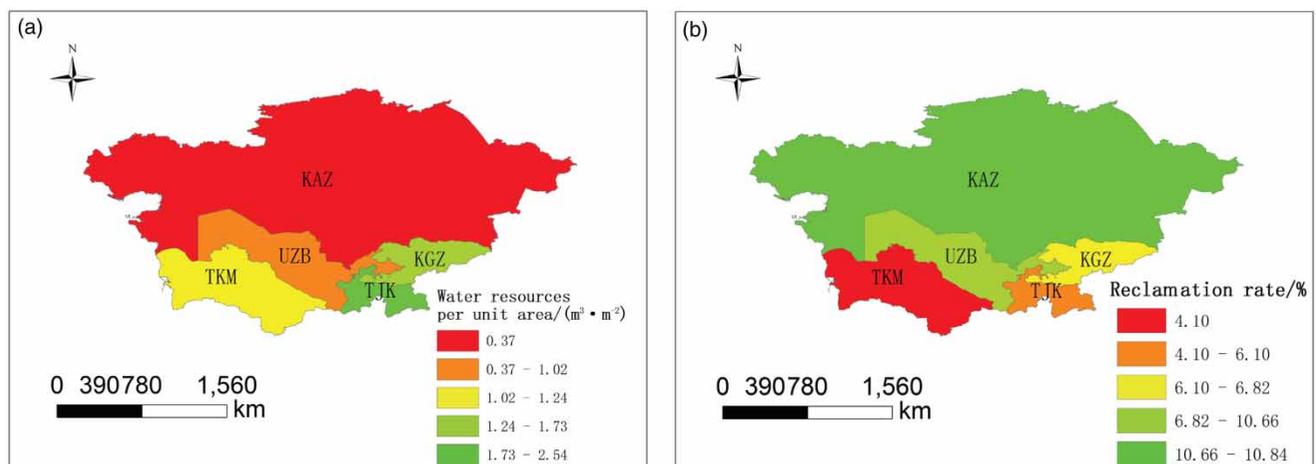

Figure 4 | Spatial distribution of water and land resources in five Central Asian countries in 2016.
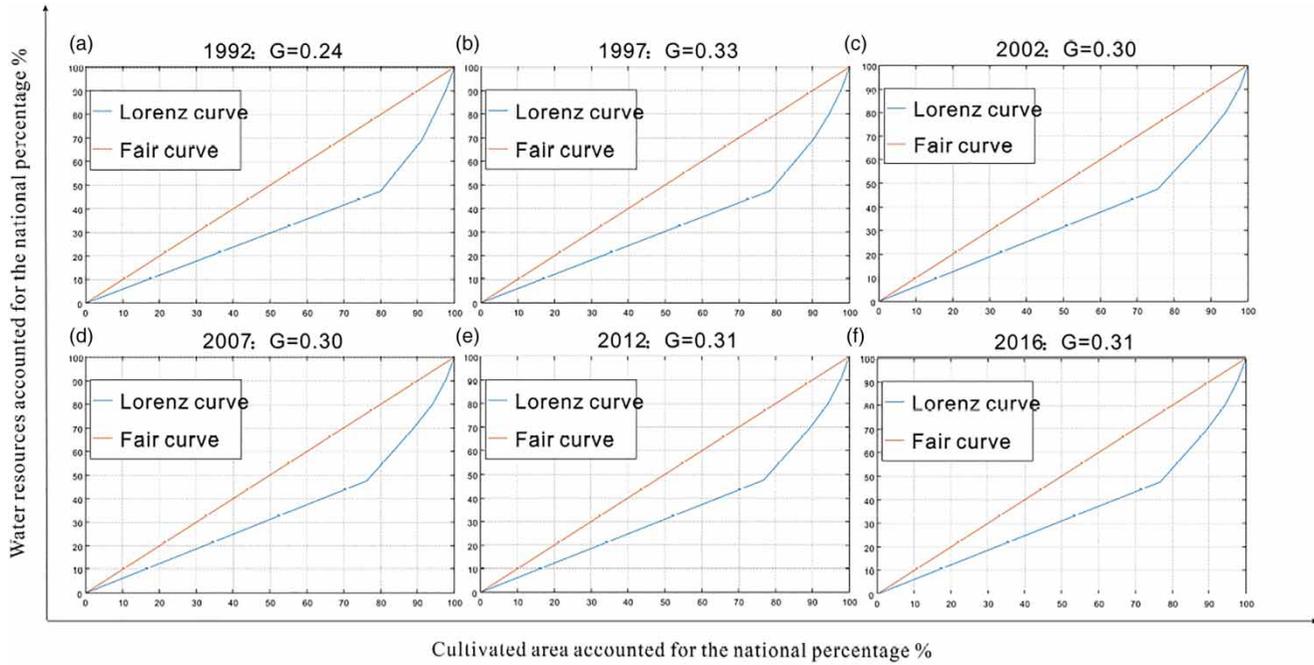
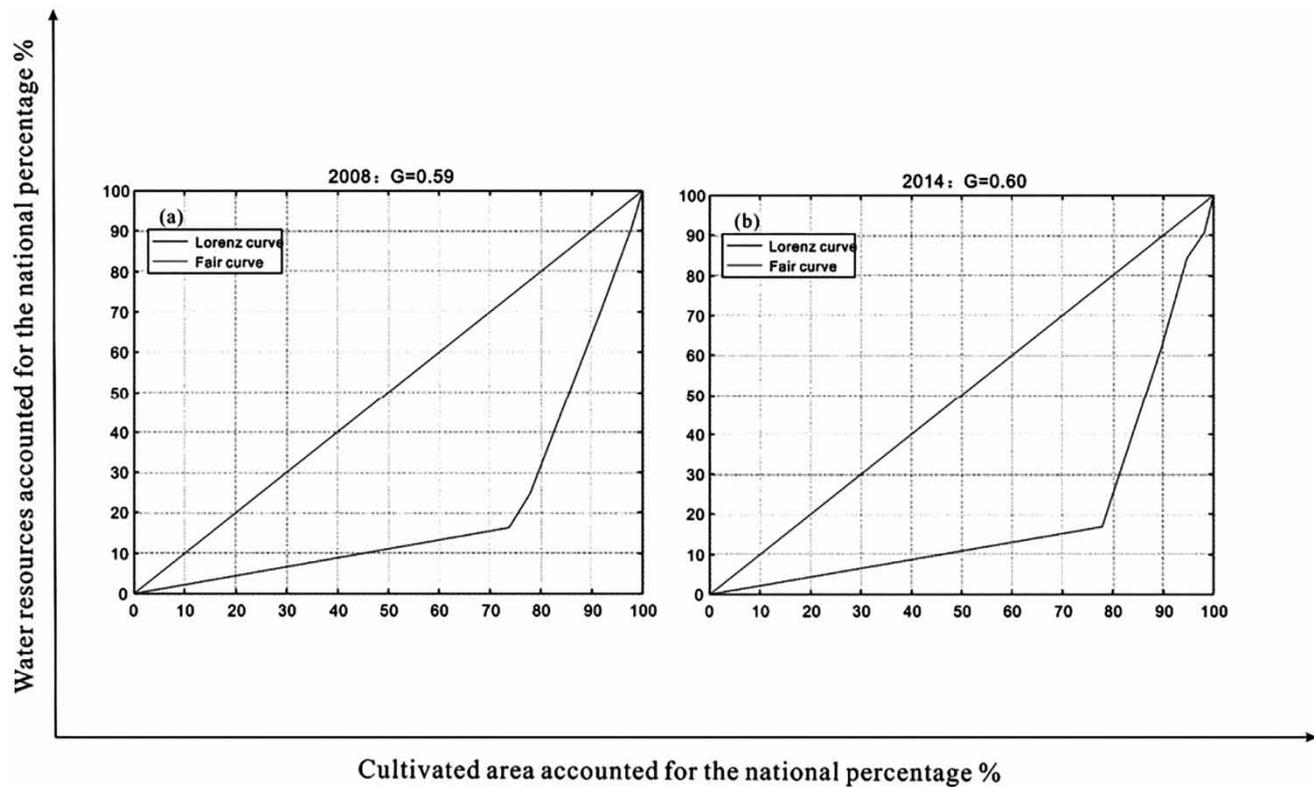**Figure 5** | Lorentz curve of water and land resource matching in Central Asia.

Figure 6 | Gini coefficient for Central Asia.

Table 3 | Matching index of water and land resources in five Central Asian countries from 1992 to 2016

Country	1992	1997	2002	2007	2012	2016	Mean
Kazakhstan	0.251	0.269	0.286	0.256	0.236	0.242	0.257
Kyrgyzstan	1.601	1.557	1.569	1.624	1.625	1.610	1.598
Tajikistan	2.054	2.198	2.279	2.284	2.281	2.310	2.234
Turkmenistan	1.565	1.349	1.138	1.109	1.164	1.164	1.248
Uzbekistan	0.943	0.949	0.916	0.938	0.926	0.922	0.932
Mean	1.283	1.264	1.238	1.242	1.246	1.250	1.254

index of water and land resources in Central Asia is 1.25 (Table 3), which is Good matching. The spatial matching pattern of water and land resources in Central Asia varies across different periods. The matching situation of each country is as follows: Kazakhstan changed from Poor matching in 2007 to Moderate matching in 2012 (Figure 7(d) and 7(e)); Uzbekistan fluctuated between Relatively good matching and Moderate matching; Turkmenistan has changed from Good matching in 1997 to Relatively good matching in 2002 (Figure 7(b) and 7(c)); Kyrgyzstan remained as Good matching; Tajikistan was Excellent matching from 1992 to 2016 (Figure 7(a)–7(f)). Meanwhile, differences exist among the matching index of water and land resources in different countries in the same period. The overall situation of Turkmenistan, Kyrgyzstan, and Tajikistan is better; the upstream countries (Kyrgyzstan, Tajikistan) are better than the downstream countries (Turkmenistan, Uzbekistan, Kazakhstan) (Figure 8).

DISCUSSION

Analysis of spatial distribution and matching pattern results

1. A clear dislocation of water resources and cultivated land resources has been identified in Central Asia. Kazakhstan is the most prominent, exhibiting low water resource per unit area with the highest reclamation rate in the region. The shortage of water resources has become the main factor restricting agricultural development in the region. Kazakhstan is not water-scarce in terms of total water supply per capita. However, the uneven distribution in space and time, in combination with excessive and often uncontrolled withdrawal for irrigation, creates water scarcity, especially in the southern area.

2. The average Gini coefficient in Central Asia is 0.32, and the matching situation of water and land resources is relatively reasonable. It shows that Central Asia is regarded as a whole and its water and land resources are balanced to a certain extent. The total renewable water resource is not a decisive factor contributing to the water problems in Central Asia. The average Gini coefficient obtained from the total water withdrawal as a parameter of water resources in Central Asia was 0.60, and the matching situation of water and land resources is Poor matching. This is in stark contrast to the results obtained from the total renewable water resource as a water resource parameter (from Reasonable matching to Poor matching). The water and land resources of Central Asia as a whole are in balance, and the contradiction of water issues mainly lies in the distribution and utilization of water resources among countries.

3. The matching index of water and land resources is a quantitative indicator for the equilibrium situation and satisfaction degree of water resources and cultivated land resources in a certain area. The matching index of water and land resources in Central Asia is 1.25, which is Good matching. However, the matching situation varies greatly among different countries. The matching situation of water and land resources in the upstream countries (Kyrgyzstan, Tajikistan) is better than that in the downstream countries (Turkmenistan, Uzbekistan, Kazakhstan). This is because, after the disintegration of the Soviet Union, the mode of free water supply to the downstream countries caused
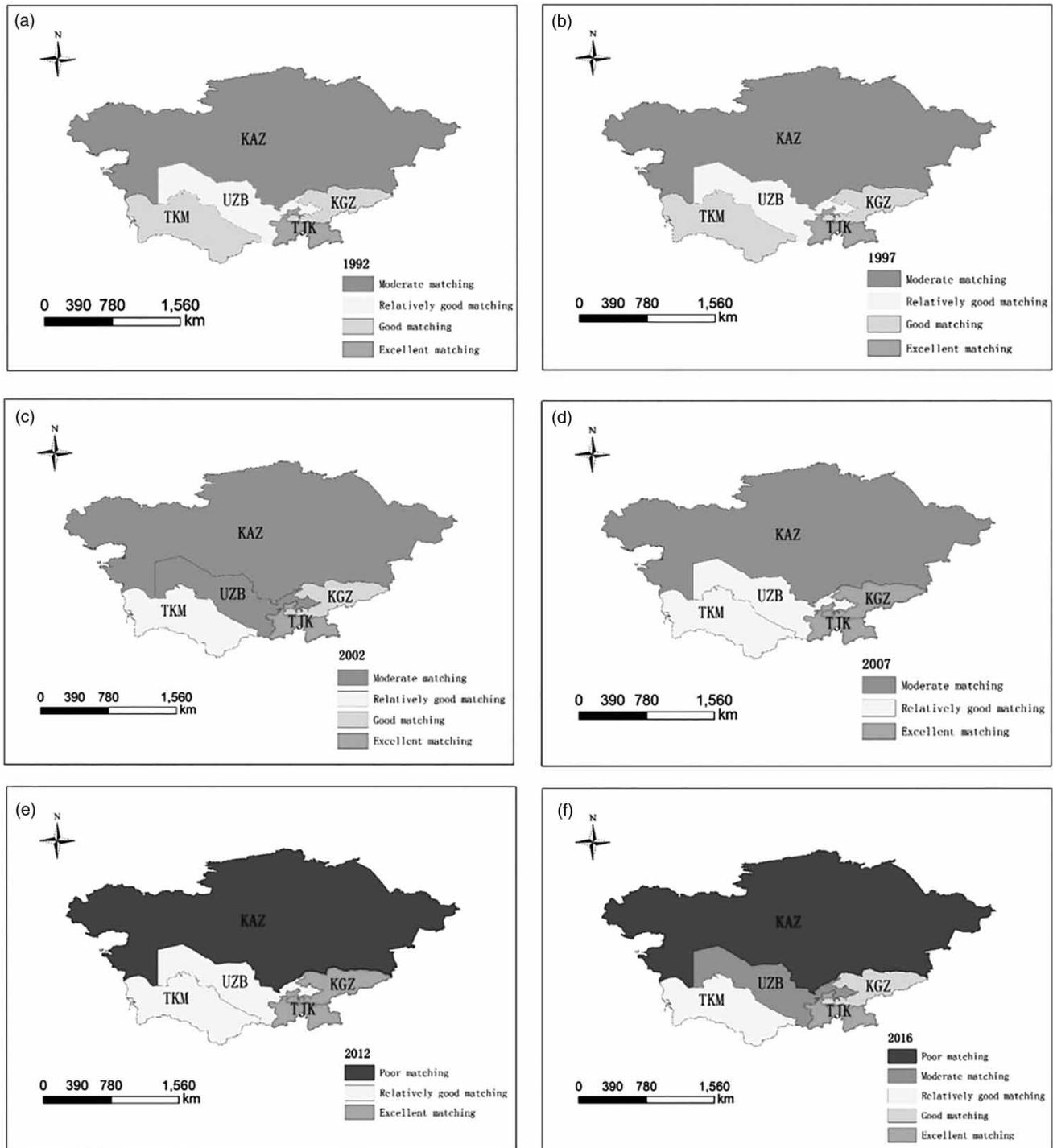
Figure 7 │ Matching index of water and land resources in five Central Asian countries from 1992 to 2016.

dissatisfaction in the upstream countries. The upstream countries to provide water and electricity for the downstream countries and the downstream countries to provide agricultural products for the upstream countries and other management systems have not been adopted.
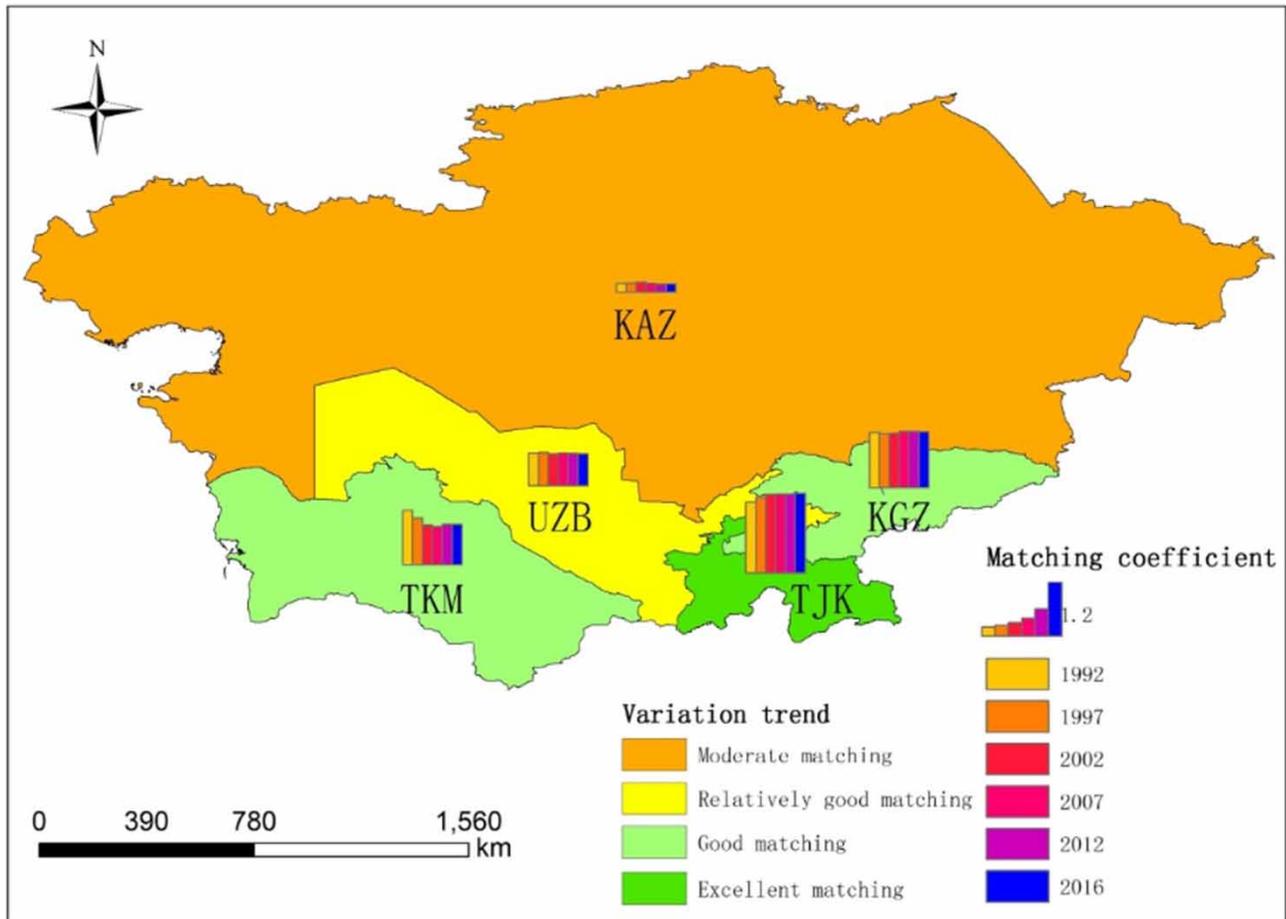
Figure 8 │ Variation trend categories of resource matching in five Central Asian.

Comparison of the two models

Two models are used in the matching of water and land resources in Central Asia. Although great discrepancies in the matching pattern are identified among the five countries, the results of the overall level of matching between water and land resources in Central Asia are reasonable. Two models both show that the matching of water and land resources are balanced to a certain extent in Central Asia. For the Gini coefficient model, the average of the matching situation is reasonable, similar to the matching degree estimated from the matching index (Good matching). In terms of the renewable water resource, the two models are almost, in the matching of water and land resources in Central Asia, reasonable. At the same time, from the perspective of each year, combining their respective evaluation criteria,

the results of the two models also show consistency. They all show the renewable water resources is not a key factor affecting water issues in Central Asia (Table 4).

Suggestions on water resource management

The Central Asian states share many common problems and unaddressed tasks in the management of water resources (Zhupankhan *et al.* 2018). Based on the current situation of water and land resources matching in Central Asia, the following suggestions are put forward.

1. Improve the water resources management and allocation system in Central Asia and formulate a scientific plan for the relative matching of water and land resources. The matching of water and land resources in Central Asian

Table 4 | Comparison of the results of the two models

	1992	1997	2002	2007	2012	2016
Gini coefficient	0.24	0.33	0.30	0.30	0.31	0.31
Matching results	Consistent	Reasonable	Reasonable	Reasonable	Reasonable	Reasonable
Matching index	1.28	1.26	1.24	1.24	1.25	1.25
Matching results	Good matching	Good matching	Good matching	Good matching	Good matching	Good matching

countries has fluctuated with time, indicating that the water resources management and distribution system needs to be improved, and it is impossible to ensure the supply of resources among countries. The present situation of water resources and future supply capacity should be combined to formulate reasonable social development strategies (Zhang et al. 2011).

2. Work out reasonable measures for constructing water conservancy projects. The future for Central Asian development lies within the intertwined use of transboundary water resources. Upstream countries use water for hydropower while downstream countries use the water for agriculture and industry. Thus, water use also needs to integrate transboundary sectors. Upstream countries produce energy that downstream countries can use for agriculture and exploiting mineral resources (Zhupankhan et al. 2018). Meanwhile, it is necessary to properly handle the contradiction of water problems and formulate reasonable water distribution, water supply, and compensation water agreements. The water contradiction in Central Asia is not the total renewable water resources, but the total water withdrawal used by various countries. The upstream countries are rich in water resources, but the matching degree of water and land resources lags behind the downstream countries. Therefore, the five Central Asian countries should consider the relevant compensation factors when formulating the transboundary water resources allocation plan.

3. Strengthen cooperation with the international community, which requires cooperation among the countries of Central Asia that goes far beyond the current situation. Major reforms are necessary and external pressures from neighboring Russia and China are likely required to make this happen (Howard & Howard 2016). Therefore, Central Asia needs to actively carry out cooperation with the international community, introduce advanced water resources management programs, draw on national policies with outstanding effects on water control, and ultimately achieve social-economic-ecological sustainable development in Central Asia.

Limitations of this study

1. The total amount of water and land resources will change due to industrialization, urbanization, water conservancy construction, and so on. Therefore, future studies should consider the dynamic changes in the matching of water and land resources in the border areas of Central Asia. At the same time, the matching of water and land resources should be refined to evaluate the micro-states of crop water demand and land use in each state, which also needs further research.

2. This paper analyzes the matching of water and land resources in Central Asia on the time and space scales. However, due to the fact that appropriate data were not available, it is impossible to estimate historical data and make scientific predictions for future data. Further research can improve this to make a more comprehensive analysis.

CONCLUSIONS

This paper takes the five Central Asian countries as the research unit, and uses the total renewable water resource and total water withdrawal as the water resources parameters, and constructs the model of the Gini coefficient and the matching index between water and land resources. Then, reasonable suggestions are put forward according to

the current situation of water problems in Central Asia. The matching situation of water and land resources in Central Asia is generally better. The average Gini coefficient is 0.32, and the water and land resources matching index is 1.25. The main contradiction of the Central Asian water problem is the distribution and utilization among countries. Therefore, relevant departments should improve the water resources management and distribution system in Central Asia, formulate reasonable water distribution, water supply, and compensation water agreements to achieve social-economic-ecological sustainable development in Central Asia.

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