Temporal and spatial characteristics of water resources in the Yeerqiang River Basin based on remote sensing

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Abstract. Surface water resources play an important role in the economic and social developments as well as the protection of natural ecological environment in the Yeerqiang River Basin. Based upon the six stages of land use data from 1990 to 2015, the temporal and spatial variation of surface water resources in the Yeerqiang River Basin have been explored and analyzed. The results show that: (1) From 1990 to 2015, the area of natural landscape initially increased and then decreased, while the area of artificial landscape increased, which caused a slight increase in the land use degree in the study area. (2) The dynamic changes of water and glacier areas are somewhat consistent over the past 25 years, with a sharp decline between 2005-2010 and a small increase in the remaining years. The dynamic changes in areas of non-glacial water were moderate, with decrease in area of 9 km² from 1990 to 2015. The beach area decreased, and the other water sub-classes initially increased and then decreased. (3) Over the past 25 years, the proportion of unchanged water area is 73.22%, the transfer-out proportion is 19.19%, and the transfer-in proportion is 7.59%. Generally, water types transferred to grassland and unused land. Additionally, significant transfers were observed for the conversions between glaciers and woodland, conversions between canal, lake, reservoir and beach, and conversions between beach and farmland.

1. Introduction
The Tarim River Basin, an area of Xinjiang with a large population, plays a significant role in the regional economic activity, ecological function, and environment protection [1]. However, ecological and environmental problems, such as water resources shortages, desert riparian forest degradation, and land desertification have presented an increasingly serious situation in the region [2-3]. Surface water resources are significant for the stable and healthy development of the ecological environment in the basin. The Yerqiang River is the longest headstream of the Tarim River, accounting for 3.6% of the all Tarim River runoff recharge; therefore, the surface water resources in the Yerqiang River Basin are representative of the surface water resources in the Tarim River Basin. Thus, we selected the Yeerqiang River Basin as the study area for this research and conducted dynamic monitoring of land use and surface water resources from 1990 to 2015. In this way, we hope that our study can assist in environmental conservation and government regulation in this region.

2. Data and methodology

2.1. Study area

The Yerqiang River is located in the western region of the Tarim Basin and is one of the main origins of the Tarim River, with river length of 1179 km. The Yerqiang River Basin is bordered on the west by the Tuohulake Desert, on the east by the Taklimakan Desert, and surrounded to the north and south by the Tianshan and Kunlun mountains (figure 1). The basin extends across four regions, including Kashi, Hotan, Kizilsu Kirgiz Autonomous Prefecture and Akesu. The total area is 9.89×104 km2, of which the mountains account for 61.5% and the plains account for 38.5% [4-5]. The Yerqiang River Basin is located in an arid region of Northwest China and belongs to the warm temperate continental plateau climate, with low precipitation and strong moisture evaporation [6].

![Figure 1. Location (B) and scope (A) of the study area.](image)

2.2. Data
The data used in this study are as follows: (1) China's rivers, administrative divisions and other basic geographic vector data; (2) Land use data (30 m raster data) of Xinjiang from 1990 to 2015. The data were generated by manual visual interpretation, using the Landsat TM/ETM/OLI remote sensing images as the data source. The data include six primary land use types (farmland, woodland, grassland, water, residential land and unused land) and twenty-five subclass land use types. The sub-class land use types of water include canal, lake, reservoir and pond (referred to as reservoir), permanent ice and snow (referred to as glacier), and beach.

2.3. Methodology
In order to research land use, especially the temporal and spatial variation of surface water resources, the land use degree index calculation formula was used to calculate the land use degree index, as presented by Liu et al. [7-8]. This index can be used to quantitatively reveal the comprehensive land use level and has an important role in reflecting the change of land use degree. Additionally, in order to determine the intensity of surface water resources changes, this study used a single land use dynamic degree [9]. Finally, a transfer matrix was used to analyze the transfer features between surface water resources and other land use types in order to elucidate the transfer source and destination of surface water resources [10].

3. Result and discussion

3.1. Regional land use change
The grassland and unused land have a large area proportion in the study area. These two land types account for 82.01% of all land use areas. Water areas account for 9.78%, followed by farmland, woodland and residential land accounting for the least, with areas 6.89%, 0.98% and 0.34%, respectively (figure 2). The types that most closely related to human activities are farmland and residential land. The area changes of these two types showed a significant increasing trend. Among them, the change in area of farmland shows a smaller reduction from 1990 to 1995, but it increased over the next two decades, with a total increase of 4295 km² (figure 2). With respect to farmland, the area of residential land showed a slow growth trend, with a total increase of 161 km² from 1990 to 2015 (figure 2). The combination of these two factors causes an increase in human consumption of regional water resources and, therefore, changes the temporal and spatial distribution pattern of regional surface water. The woodland, grassland and unused land in the study area were affected less by human activities but affected more by natural environment. Woodland was the low proportion type in the study area. The woodland area first increased and then decreased, with a total increase value of 89 km² over 25 years (figure 2). The change in grassland area increased from 1990 to 1995, but later it decreased a total of 5941 km² over 20 years (figure 2). The area of unused land fluctuated irregularly from 1990 to 2015 (figure 2).

The land use degree index can quantitatively describe the comprehensive level of regional land use and indirectly reflect the degree of regional water consumption. The land use degree index of the study area was affected by the combined effects of land use/cover changes and initially showed an increasing trend, followed by a decrease. The total increase in index value was 1.77 over the last 25 years; the minimum value was 151.15 in 1990 and the maximum was 154.48 in 2005 (figure 2). In
addition, although the land use degree in the study area increased, the average value of the land use
degree index was 152.63, which is significantly smaller than the limit value (400). On one hand, it is
closely related to the high proportion of unused land (accounting for 54.64% of the total) in the study
area, and on the other hand, it shows that the land use degree and development intensity of this study
area remained relatively low between natural and agricultural land use.

![Figure 2](image_url)

**Figure 2.** Changes in regional land use in the study area from 1990 to 2015.

### 3.2. Dynamic change characteristics of water

The land use single dynamic degree can be used to study the dynamic changes of the water areas. More specifically, it can reflect the severe degree (amplitude and velocity) of the change in water areas in the study area. The glacier category is the dominant water type in the study area, and it accounts for 92.28% of the total water area. Therefore, the overall change in water area was consistent with that of the glacier area. The glacier category showed a slight increase in area from 1990 to 2005, and later it sharply declined, with an area reduction of 5097 km² from 2005 to 2010. Although, in the last five years, the area slightly increased (figure 3). Compared with the glacier, the change non-glacial water area was relatively slow, and it fluctuated, with a total area decrease of 9 km² over the last 25 years (figure 3). The canal area also fluctuated, reaching a maximum value of 413 km² in 1995 and a minimum value of 243 km² in 2005. The total area increased to 25 km² for the canal area (figure 3). The lake area first increased, and then decreased from 1990 to 2010. Later, the lake area increased sharply to 166 km² from 2010 to 2015, and the dynamic degree reached 30.74% (figure 3). The reservoir area significantly increased after an initial decreasing trend, and the minimum value was 206 km² in 1990. The maximum value for the reservoir area was 360 km² in 2000 and 253 km² in 2015 (figure 3). The beach area increased slightly from 1995 to 2000, and yet in the rest of the periods the areas were reduced. The greatest reduction was observed from 1990-1995, with an area decrease of 200 km². Ultimately, the beach area showed a total reduction of 240 km² over the last 25 years (figure 3).
3.3. The transfer characteristics of water areas

Through quantitative analysis of the dynamic change in water area, we know that the water area first increased and then decreased from 1990 to 2015. The water area decreased to 2190 km²; the glacier area decreased to 21810 km²; and the non-glacial water area decreased to 90 km². In order to identify the location and the associated land use/cover types of these changes, the transfer rule between water types and other types in the study area were obtained by statistical analysis based on the six stages of land use data. In the past 25 years, the proportion of non-change water area is 73.22%, and total transfer water area is 26.78%, of which 19.19% is water transferred into other types and 7.59% are other types transferred into water (figure 4). The areas in water categories transferred mainly into grassland and unused land, and the transfer proportions were 30.14% and 66.74%, respectively. The total was 96.88%, and the remaining water categories were mainly transferred into farmland, with a proportion of 2.86% (figure 4). Similarly, the types that transferred into water were mostly grassland and unused land, and the transfer proportions were 26.76% and 71.03%, respectively. The total was 97.79%, and the remaining water categories were mainly transferred from farmland with a proportion of 1.66% (figure 4). We observed the transfer changes between water and other types mainly occurred in the glacier region, and those types were mainly grassland and unused land. In addition, in the low altitude plain area, a large number of non-glacial water converted with farmland and woodland, with the exception of grassland and unused land. The transfer law between water and other types in local research stages is more consistent with that of 25 years. The proportion of the un-changed water area decreased from 85.26% in the 1990-1995 stage to 72.05% in the 2010-2015 stage. The proportion of the transfer area of water in each local period is large, but there is no uniform law. However, there is a phenomenon that the proportion of the water transferred into farmland is greater than the farmland transferred into water, and this indicates that water areas were developed into farmland in the past 25 years.
3.4. The transfer characteristics of water sub-classes

Before, we calculated the transfer rule between water and other types, but the transfer relationships between sub-class water and other types are not clear. Therefore, in order to further analyze the transfer characteristics (transfer destination and source) of sub-class water, we constructed an area transfer matrix. In all the sub-classes of water, the glacier category is considered solid surface water, and its area was larger than other water sub-classes. It also plays an important role in the regional runoff and reservoir water supply. In the past 25 years, the glacier area was unchanged at 12912 km$^2$, and the transfer area of glacier to other types is 3345 km$^2$. Of the 3345 km$^2$, 961 km$^2$ and 2384 km$^2$ were transferred into grassland and unused land, respectively (figure 5). In addition, the glacier category is exclusively transferred from grassland and unused land with 206 km$^2$ and 959 km$^2$, respectively (figure 5). In the five local stages, the types that mutually transferred with glacier are still dominated by grassland and unused land; however, some transfer with canal and woodland categories was observed. Canal refers to man-made or natural forms of water reservoirs, with linear characteristics and permanent location below the water surface curve. As the main type of sub-class non-glacial water, canals are important representatives of regional water resources. In the past 25 years, the area of the canal category was unchanged at 105 km$^2$, and the net conversion area from woodland, grassland and unused land to canal are 2 km$^2$, 29 km$^2$ and 16 km$^2$, respectively. The net conversion area from canal to farmland, lake and beach are 3km$^2$, 3km$^2$ and 17km$^2$, respectively (figure 5). The transfer relationships between canal and other types in local research stages are more consistent with

![Figure 4. The transfer destination of water from 1990 to 2015 in the study area.](image)
that of the past 25 years. The main types mutual transferred with canal were grassland and beach. Lakes and reservoirs are both water storage facilities, and the difference between them is the origin of formation: natural or anthropogenic. Lake is irregular in boundary shape. Reservoirs are a kind of surface water body, which are constructed with obvious artificial features, hydraulic structures and dams. In the past 25 years, the area of lakes remained constant at 94 km², and the transfer source was mainly grassland, with a net transfer-in area of 23 km². The transfer destination was mainly beach, with a net transfer-out area of 111 km². The area transferred to other types was small and no more than 10 km² (figure 5). Compared with the transfer changes of the lake, the transfer changes of the reservoir were more severe. In the past 25 years, reservoir area remained constant at 117 km², and the transfer destination was mainly from reservoir to farmland and lake, with net transfer-out areas of 31 km² and 18 km², respectively. The transfer sources were mainly grassland and beach, with a net transfer-in area of 29 km² and 63 km², respectively (figure 5). In the local stages, there were more transferred areas between reservoir and beach, and beach predominantly transferred to lake. As one of the sub-classes of water, beach is defined as the land between the water surface curve of flood season and dry season. For most of the year, it is a surface area without water; therefore, beach is special compared with the other subclass water types. In the past 25 years, the beach category remained constant with an area of 228 km², and beach areas transferred into lake, reservoir and farmland were 111 km², 63 km² and 45 km², respectively (figure 5). There are also 35 km² of net beach transferred to grassland, and the transfer area to woodland and unused land were small (figure 5). It is interesting to note that only canal area transferred into beach, with an area of 17 km².

Figure 5. The transfer destination of sub-class water from 1990 to 2015 in the study area.
4. Conclusions
In this study, we quantitatively analyzed the dynamic changes of surface water resources in the Yeerqiang River Basin from 1990 to 2015. This study revealed surface water resources changed greatly over this time period, especially the transition changes in grassland, unused land and farmland. The changes were significantly influenced by human activities, in particular agriculture activities. The results of this study can offer useful insight to land use and surface water resources conservation as well as provide valuable information to policy makers, promote the implementation of the “The Belt and Road” program, and assist in regional environmental conservation and sustainable development.

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