

Emergy analysis of ecological water resources in Tarim river tail region

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Abstract: The lower reaches of the Tarim River (Chala-Taitma Lake) is a typical ecologically fragile and sensitive area in the arid river basin. By 2017, 17 ecological water conveyances have been continuously implemented in this area, and the accumulated ecological water supply has exceeded 6.11 billion m³. It's necessary to know change of the Taitema Lake after ecological water transportation. This study investigate the dominant ecological processes on emergy analysis methods and analysis the renewable emergy change of the Taitema Lake. The results are as follows: (1) Water is the dominant ecological factor in the region, and water resource metabolism is the dominant process in the region's ecosystem evolution. The evolution from desert to lake and wetland ecosystem is the main pattern of ecological water transportation in this area.(2) According to the calculation of the renewable emergy of the Taitema Lake in 2016, the total renewable emergy input is 3.53×10^{20} sej, in which the solar emergy takes up the largest proportion of the total emergy input, which is up to 74.39%.(3) Before 2000, the renewable emergy input in this region tended to decrease. By 2000, there was a significant growing. After 2000, the renewable emergy of the Taitema Lake shows a increasing trend.

1 Introduction

The Tarim River, the largest inland river in China, originates from the Tianshan mountain and Karakoram mountains and flows into the Taitma Lake in the southeast of the Tarim Basin.

The size of Taitma Lake, which is tail region of the Tarim River, is an indicator of the river's water volume. In the 1950s, there was about 80 km² area of the lake. Since 1972, the channel of the Lower Tarim River has reduced to nothing with a length of 363km below the Daxihaizi reservoir. The Lake dried up and it has quickly been buried by the desert. The vegetation in the lake area was also dying and the ecological environment was becoming worse. The lake was buried by salt crust, and the ecosystem structure was destroyed, with the biodiversity being reduced.

In order to changing this situation, the ecological water transfer to the Lower Tarim River began since on May, 2000. The water was first successfully transported to Taitma lake until April to November 2001, after the first two deliveries failed, and nearly 400 million m³ water were carried to the area. By the end of 2017, 18 ecological water transportation has been carried out and more than 6.88 billion m³ water has been transported to the area, which make the lake area exceeding that of historical

records. There is about 511 km² lake and wetland area. After ecological water transportation, The ecological environment of Taitma Lake has been improved day by day and the biodiversity has increased, while it has effectively stopped the tendency of the convergence of the Taklamakan desert and the Kurutaka desert.

Although ecological water transportation have been carried out, the assessment on the ecological effect of water delivery has not been made, and the changing trend of the ecological environment of the Taitema Lake area cannot be valued and predicted.

About ecological effect of water transportation at home and abroad, some scholars have been researched. Deng (2007) has established a scientific evaluation system for the characteristics of vegetation restoration in the Lower Tarim River, and constructed the concept of relative recovery degree to conduct quantitative evaluation of vegetation restoration. Gui (2007) have studied the ecological response and ecological water security of Euphrates poplar forest in the Lower Tarim River after emergency water supply. Wang(2012) has account for ecological economic value of *Populus euphratica* based on the biomass in the Lower Tarim river. Abdirahman·Halik(2012) has studied Damaged ecosystem restoration and ecological effects in arid area taking lower reaches of Tari m River as an example. Ren (2013) calculated and analyzed the ecological economic

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benefits of vegetation response after the ecological water transportation in the Lower Tarim River. Liu(2018) Simulation of sectional groundwater level variation in the lower reaches of Tarim River under intermittent ecological water conveyance. Zulpiya (2018) evaluated the value of forest ecosystem services in the Lower Tarim River by economic value quantification, and the value of ecosystem services in the region was 216.78 x 108\$, and it showed a downward trend from 1972 to 2015. The above studies used different methods to analyze and evaluate the ecological effects, including vegetation restoration, nutrient transportation and groundwater response. However, these achievements are mostly carried out through economic value quantification, which is affected by factors such as market price, human preference and commodity attribute, so it is difficult to accurately assess the real value of natural assets and environmental resources.

Based on the emergy theory and analysis method, this study investigated dominant ecological process and ecological factors of Taitema Lake. Then, the emergy system diagram of the Taitema Lake has been drawn. The key ecological effect of water transportation has been analyzed from supplier perspective, and accounted renewable emergy input to the response of ecological water transportation. The study will provide big support for efficient ecological water scheduling in the Tarim

River Basin.

2 study area

The Taitema lake lie on about 45km northeast of ruoqiang county, the southeastern of the Tarim basin. The lake received the water from the Tarim River and Cheerchen River(Figure 1).

The climate around this area into deep desert is very extreme arid and it belongs to the warm temperate zone. According to recent meteorological observation data from Ruoqiang county, it show that the annual average precipitation and average temperature are 17.4 mm and 11.5°C, respectively. The annual evaporation is up to 2902.3 mm. The annual drying degree is 63.0 and the sunshine time is about 3103h per year. The frost free period is about 233 days. Under the influence of Mongolian high pressure, a single northeast wind prevailed throughout the year, with an average annual wind speed of 28 m/s and an annual wind day is about 37(wind speed > 17.2 m /s).The annual number of sandstorm days is 12.9, and the number of floating dusty days is 122.4. The annual wind speed which makes sands floating over 5.0 m/s is 1074 times. From March to September in a year, the surface earth can be blown and eroded for 8 months.

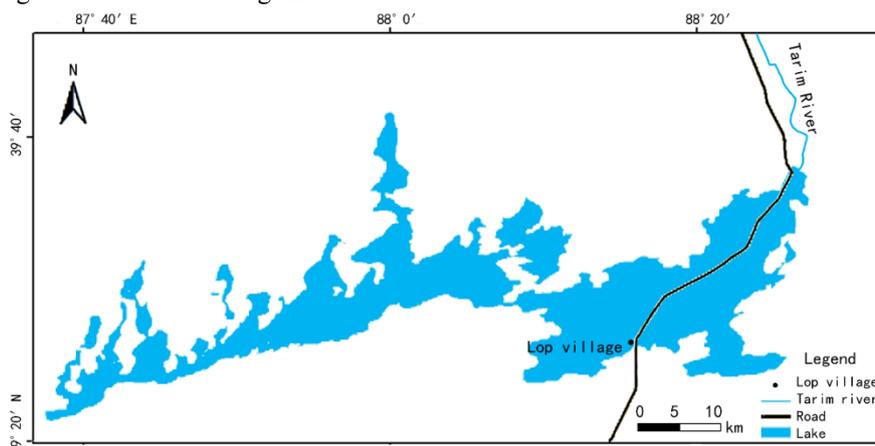


Figure1 the Taitema Lake in 2016

The natural landscape around the Taitema Lake is represented as gobi, desert, and sand mounds. The earth surface are dominated by fine sand and sediments. The natural environment is very bad and it is very difficult for the plants to survive.

During the historical period, the lake was on the middle of the Tarim, Cheerchen and Qiemo rivers. After 1972, the Lower Tarim river dried up for a long time. Since the water transportation of the Tarim river began to carry out from 2000, the lake has gradually recovered. In the past, a small amount of water from the Cheerchen river can reached the lake. In recent years, generally there was no water flowing into the lake because of excessive water diversion in the middle reaches of the Cheerchen river.

With the advance of ecological water transportation, the trees, shrubs and grasslands in the Taitema lake area were gradually restored. The trees are mainly populus euphratica and desert date. The shrubs includes sacsaoul, tamarix and black thorn. The grass contains reeds, alhagi,

and other plants. The vegetation species have grown to 46 kinds after ecological water transportation. While the number of animals in the lake area is also gradually increasing, and there are rabbit, lynx, gerbil, rodent, sand lizard and other animals. And nearly 30 species of birds such as red-beaked duck, red-billed gull, grey crane, and whisker finch lives here. Besides, 11 species of fish such as flat-beaked fish, tarim harpy fish and snout fish lives in the lake. The previously unseen white-tailed ravens, red foxes, and wild boar also reappeared (<http://www.xjepb.gov.cn>).

3 methods and sources

3.1 data sources

The data of this study on ecosystem evaluation are multi-sourced, mainly obtained from the survey reports of the

management or scientific research departments, the bulletin on water resources, the statistical yearbooks, the compilation of thematic materials, and the related literature of the study area. Considering data validity and accuracy, the items of data include lake area, wetland area, the average amount of solar radiation, average wind velocity, average rainfall, average evaporation, runoff amount, water amount of transportation, vegetation species, animals species

3.2 methods

Emergy analysis method is a scientific theory proposed and developed by the famous American ecologist H.T. Odum in the 1990s. It puts energy as the core and emergy as benchmark. The energy flow and material flow, which are originally difficult to measure in a unified system, were calculated by changing them into emergy. The emergy was provided as a common metric for comprehensively measuring the environment, resources and economy to express the true value (Odum, 1983, 1986).

Transformities are used to convert energies of different types to Emergy of the same type. Transformities for many types of energy, resources, and goods have been calculated in previous studies (Arding and Brown, 1991). The unit of standard emergy is solar emjoules, with the abbreviation of sej. The conversion equation is as follows:

$$EM = \tau \times B \quad (1)$$

In it, EM means emergy (sej). τ represents transformity (sej / J or sej / g). B represents the amount of energy or substance.

In this research, the first step is to construct systems energy flow diagrams of the Taitema Lake ecosystem, which are means of organising relationships between components. The second step is to construct emerge analysis tables based on the diagrams. The third step involves comparing the calculation results. The last step is to analyze and explain the causes of changes.

4 results

4.1 Emergy analysis of the Taitema Lake ecosystem

The tail region of the Tarim River is a relatively closed natural ecosystem with less human disturbance. Figure 2 is the emergy system diagram of the Tarim River. The emergy input from nature includes solar, wind, the chemical emergy and potential emergy of precipitation, the chemical emergy and potential emergy of runoff. These materials and energies act on the unique geography condition including geology, topography, lithology, etc. Under their combined action, deserts, wetlands and lakes have been formed.

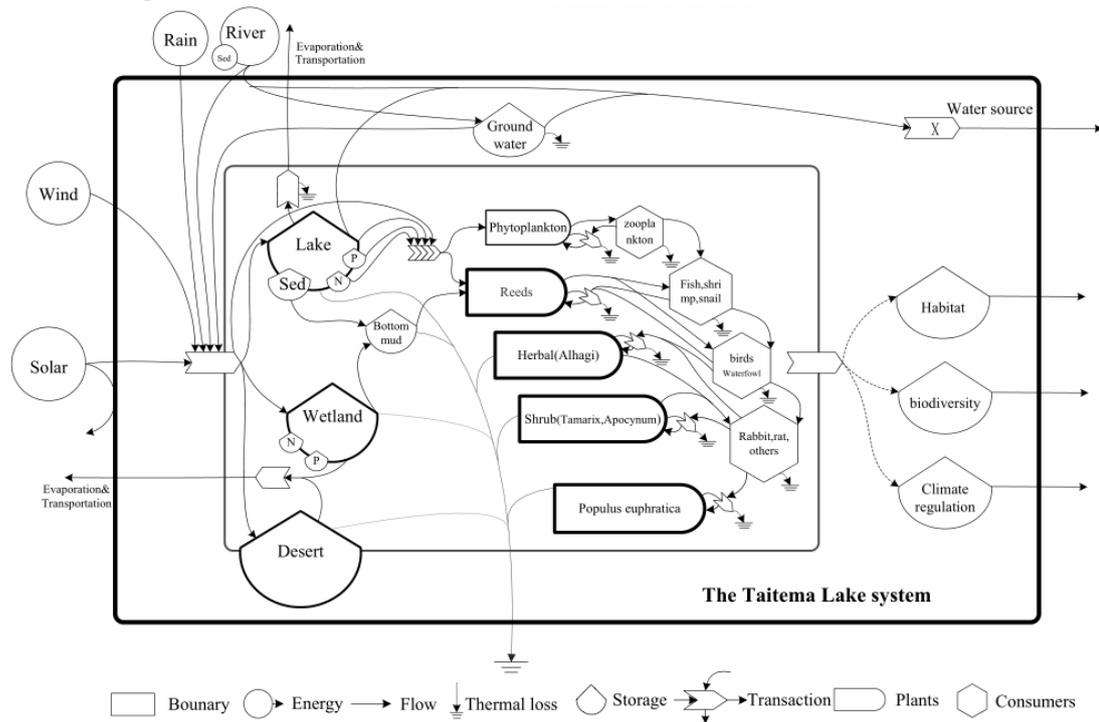


Fig.2 Emergy system diagram of the Taitema Lake

Because insufficient runoff for many years in the Lower Tarim River, the Taitema Lake lost its water source for a long time, and the evaporation of the region was far greater than precipitation. The lake gradually shrank and dried up, and the wetland degraded. The original lake and wetland evolved into desert. For example, from 1983 to 1997, the lake was completely dried up. The bottom of the lake became sand sea and salt crust, under which are fine sand and silt being easy to erode by winds. Besides, the

underground water level drops sharply. Trees and shrubs such as populus chinensis and tamarix have been in severe decline, with herbs disappearing. Birds and animals in this area had to migrate or even died.

After many times water transportation were carried out for nearly 20 years, the sand area of tail area of the Tarim River has decreased significantly, and the natural vegetation has increased a lot. The ecological environment of the Taitema Lake has improved obviously. In relatively

low-lying areas, a large area of the lake is formed, surrounded by wetlands, which include swamps and beaches.

When the water transportation happened, the water level of the river or lake is higher than the underground water level, and the groundwater was supplied, then the groundwater level rises. At the same time, the mineral degree of the groundwater decreases and the water quality is improved, which can provide water source for organisms.

In the lake ecosystem, sediment, nitrogen and phosphorus carried by water, which provide nutrients for organisms. In the swamps and floodplain areas around the lake, some herbaceous plants such as reeds, liquorice, camel's thorns, shrubs such as Robins, tamarix, black thorns, and trees such as populus euphratica, barracuda and barracuda are mainly grown. Generally speaking, in this area vegetation is relatively unitary and plant community structure is very simple. After vegetation restoration, some animals gradually began to appear. The zooplankton in the lake began to recover, fish, shrimp, snails and other aquatic creatures came out, and some ducks, black storks and other waterfowl, rabbits and gerbils can be seen. Ecological functions of providing

water, regulating climate, providing habitat for animals and plants, and maintaining biodiversity of the lake's ecosystem has gradually restored.

4.2 Emery accounting of the Taitema Lake ecosystem

4.2.1 area changement of the Taitema Lake in last 60 years

Fig. 3 shows the annual change of the Taitema lake area in the tail region of the Tarim River in the last 60 years. According to figure 3, the largest area of the lake was 511km² in 2017, followed by 507.1 km² in 2012. The area of the lake varies greatly from year to year, and from 1959 to 1979 shows a downward trend. In 1980-1988 is in a dry state, and the lake area is very small until 1999.

In 2000, the Tarim river began to carry out intermittent ecological water transportation. and then the lake area rose. From 2000 to 2006, the average area was 138.41 km². After 2009, the area rose sharply and it reach the biggest in 2017.

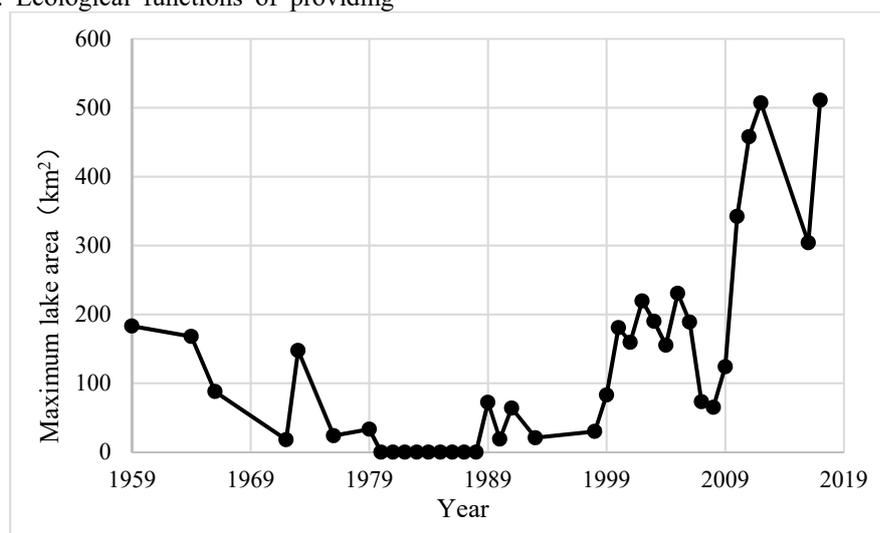


Figure 3 the annual maximum of the Taitema Lake area in last 60 years(no data in 2013-2015)

4.2.2 Emery accounting of the Taitema Lake ecosystem

As can be seen from figure 2, the renewable emery of the Taitema Lake are mainly solar emery, wind emery, evaporation emery, rainwater potential emery and chemical emery, as well as the river potential emery and

chemical emery. Table 1 shows that the total renewable emery input the Taitema Lake in 2016 was 3.73×10^{20} sej, the evaporation emery output was 2.00×10^{19} sej, and the net emery value was 3.53×10^{20} sej. Among the renewable emery input, the solar emery value is the largest, 2.78×10^{20} sej, accounting for 74.39% of the total emery input. While the Wind emery is minimal.

Table 1 the renewable emery of the Taitema Lake in 2016

Item	Unit	Raw data	UEV (sej/unit)	Solar emery(sej)
Solar	J	2.78E+20	1	2.78E+20
Wind	J	9.93E+11	8.00E+02	7.95E+14
Rain geopotential	J	2.20E+15	7.00E+03	1.54E+19
Rain chemical potential	J	9.24E+14	7.00E+03	6.47E+18
River geopotential	J	1.99E+14	1.28E+04	2.54E+18
River chemical potential	J	3.34E+15	2.13E+04	7.11E+19

Evaporation	g	8.82E+14	2.26E+04	2.00E+19
Total				3.53E+20

Figure 4 shows the changes of renewable energy in the Taitema Lake in 1990, 1995, 2000, 2005, 2010 and 2016. Before 2000, the renewable energy input of the

region was decreasing trend. By 2000 there was a significant increase. Since 2005, renewable energy increased gradually.

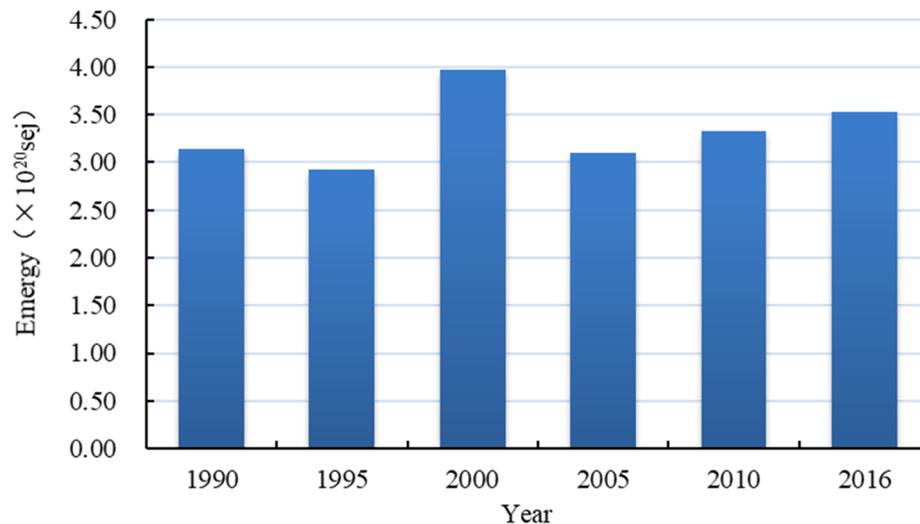


Figure 4 the changement of renewable energy in the Taitema Lake

5 Conclusions and Discussion

In this research, dominant ecological process and ecological factors in the Taitema Lake has been investigated. Based on the energy analysis method, from the perspective of the supplier, the energy system diagram of the Taitema Lake has been drawn. The renewable energy input to the response of ecological water transportation has been accounted. The conclusions drawn are as follows:

(1) Water is the dominant ecological factor in the region, and water resource metabolism is the dominant process in the region's ecosystem evolution. The evolution from desert to lake and wetland ecosystem is the main pattern of ecological water transportation in this area.

(2) According to the calculation of the renewable energy of the Taitema Lake in 2016, the total renewable energy input is 3.53×10^{20} sej, in which the solar energy takes up the largest proportion of the total energy input, which is up to 74.39%.

(3) Before 2000, the renewable energy input in this region tended to decrease. By 2000, there was a significant growing. After 2000, the renewable energy of the Taitema Lake shows a increasing trend.

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