Research of the Sustainable Development of Tarim River Based on Ecosystem Service Function

Xiang Huang a, Yaning Chen a, Jianxin Ma a,b, Xinming Hao a,a*

a State Key Laboratory of Desert and Oasis Ecology, Xinjiang Institute of Ecology and Geography, Urumqi, 830011, China; b Graduate University, Chinese Academy of Sciences, Beijing 100039, China

Abstract

The characteristic of change in value of Tarim River ecosystem service function and its causes are probed by the means of combining the remote sensing images with social statistical data related to the change in land utilization of Tarim River trunk stream area during 1973-2005. The research results reveal the relationship between the economy and ecology and the sustainable development of Tarim River. a situation of linear ascension in the value of Tarim River ecosystem service function over the past thirty years, among which, the economic value of the Cropland ecosystem service function is increased to the greatest extent, far in excess of other types of ecosystem system. The ecosystem of grassland shows a downward tendency relatively both in service supply capacity and in value contribution. The area of Cropland ecosystems increases while that of grassland ecosystems decreases. This fact indicates that the integral capacity and balance of the ecosystem in the region investigated have been affected severely and the ecosystem has deteriorated.

Keywords: Ecosystem service function, value, Tarim River, ecological degradation

Ecosystem is the foundation upon which human beings survive and their community civilization develops (P.J.O’Farrell, et al.2007). The products and service provided due to the ecosystem service function furnish the necessary environmental conditions and process in order to meet the requirements of human beings (Costanza R, et al.1997). Therefore, the maintenance and protection of ecosystem service function is the essential for achieving the harmony and balance between human community and ecosystem. The study and evaluation value of ecosystem service function and its change has become one of the hot spots in ecology and economics at present (Bin Zhou,2004). And more research of the sustainable development. However, few of them focus on the relationship between the sustainable development and the ecosystem function (Chunfu Tong, et al.2007; Jukka Matero,2007). In view of ecosystem rehabilitation and sustainable development, the more we know about the economic value of various ecosystem service functions, the
more we understand the importance of theirs. Therefore, the evaluation on the value of arid-area ecosystem service function can help in estimating the ecosystem balance and its integrity, which ultimately promotes the harmonious development of society and ecosystem.

Tarim River Basin in west arid area is the biggest endorheic river valley in China and one of the most important bases of petroleum, typical Percent in Xinjiang(Xu Hailiang, et al, 2005). This region is abundant in resources but its ecological environment is very fragile with a sharp conflict between economic development and ecological environment (Wang Ranghui, et al, 2000). While taking the trunk stream of Tarim River as the subject investigated, this paper has made a systematical investigation and research on the relation between ecosystem service function and anthropic activities, based on the dynamic change of ecosystem area and unit value, as well as the impact of the change in land utilization in this area on the value of ecosystem service function value.

1. General Situation of Region Investigated

Being located on the north edge and in west of Taklimakan Desert, the trunk stream of Tarim River is 1320km long. The region is of typical continental climatic characteristics, arid with little precipitation and intensive evaporation. There are 11 soil groups, 23 subgroups and 47 local types of soil in the region of Tarim River trunk stream. The full length is 1320km and the gross area $4.09 \times 10^4$ km$^2$ (Fig. 1) In line with administrative division, the region covers part or the whole of Akesu city, Shaya County, Xinhe County and Kuche County under Akesu Prefecture, Luntai County, Korla City, Yuli County, Ruojiong County under Bayinguoleng Mongolian Autonomous Prefecture, Xinjiang Uygur Autonomous Region, and 15 Agricultural Regiment under Agricultural Division No. 1 (Regiment No. 7, 8, 9, 10, 11, 12, 13, 14, 15 and 16) and Agricultural Division No. 2 (Regiment No. 31, 32, 33, 34 and 35) of Xinjiang Production & Construction Corps.

2. Material and Approach

2.1. Data acquisition

The ecosystem area of the region investigated is represented by the data of land-use types based on the MSS image made in 1973, the land-use map of 1:100000 aerial remote sensing $^{[10]}$ made in 1983, the TM image made in 1990 and 2000 and CBERS image data in 2005. Different processing modes are used for processing the data source of different periods. While the topographic map of 1:100000 is processed with projection processing and used as the master data source, a remote-sensing interpreting sign of corresponding land coverage type is established on GIS platform with combination of aerial remote-sensing land-use map of 1983 and TM (ETM) data of 2000 in register. The image data of 1973, 1990 and 2005 are rectified on the basis of TM image data of 2000, and the mean position error is controlled within
two pixels. An interrelated interpretation both by men and computers is implemented in turn based on land-use data of 1983 with the support of Arc/Info software, and the dynamic map spots of changes in various land-use types during two successive periods are selected and collected. Thus, dynamic data of land use during different periods is obtained. At the same time, the data of ecosystem area in 1973, 1983, 1990, 2000 and 2005 are obtained, too.

Based on the previous research results about land-use and ecosystem service function at home and abroad (Luo G P, et al, 2008; Song Kaishan, et al,2008), and combining the hydrological and ecological characteristics with artificial intervening strength in this region, the research based on the change of cropland and grassland ecosystem types. Those 5 ecosystems interpreted with CBERS data of 2005 are rectified with large numbers of field spots which are selected at random, and ultimately the interpretation precision of all ecosystem areas is above 85%. Therefore, the requirement on analysis of large-area ecosystem area is satisfied.

2.2. Equivalent determination

Equivalent Factor Table of Chinese Terrestrial Ecosystem Service Value (Table 1) is established by combining the classification of ecosystem types in this region and on the basis of “Equivalent Factor Table of Chinese Ecosystem Service Value” by Xie Gaodi et al (Xiao Yu, et al,2003). The economic value of natural annual grain output of 1hm² cropland with annual output nationwide is defined as 1 in this table; the equivalent factor of other ecosystem ecological service value refers to the ratio of contribution by the ecosystem’s ecological service to that by cropland’s grain production service.

Table 1 Equivalent Factor Table of Chinese Terrestrial Ecosystem Service Value

<table>
<thead>
<tr>
<th>Content</th>
<th>Forest</th>
<th>Grassland</th>
<th>Cropland</th>
<th>Wetland</th>
<th>Useless land</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>3.5</td>
<td>0.8</td>
<td>0.5</td>
<td>0.9</td>
<td>0</td>
</tr>
<tr>
<td>B</td>
<td>2.7</td>
<td>0.9</td>
<td>0.89</td>
<td>8.78</td>
<td>0</td>
</tr>
<tr>
<td>C</td>
<td>3.2</td>
<td>0.8</td>
<td>0.6</td>
<td>17.94</td>
<td>0.03</td>
</tr>
<tr>
<td>D</td>
<td>3.9</td>
<td>1.95</td>
<td>1.46</td>
<td>0.86</td>
<td>0.02</td>
</tr>
<tr>
<td>E</td>
<td>1.31</td>
<td>1.31</td>
<td>1.64</td>
<td>18.18</td>
<td>0.01</td>
</tr>
<tr>
<td>F</td>
<td>3.26</td>
<td>1.09</td>
<td>0.71</td>
<td>2.495</td>
<td>0.34</td>
</tr>
<tr>
<td>G</td>
<td>0.1</td>
<td>0.3</td>
<td>1</td>
<td>0.2</td>
<td>0.01</td>
</tr>
<tr>
<td>H</td>
<td>2.6</td>
<td>0.05</td>
<td>0.1</td>
<td>0.04</td>
<td>0</td>
</tr>
<tr>
<td>I</td>
<td>1.28</td>
<td>0.04</td>
<td>0.01</td>
<td>4.945</td>
<td>0.01</td>
</tr>
</tbody>
</table>


2.3. Parameter rectification

\[E_{jr} = e_j E_{jc} \quad (j=1, 2, 3, 4, 5;)

Where, \(E_{jr}\) is the unit price of service of \(j\) ecosystem types in the region investigated; \(e_j\) is the parameter of \(j\) ecosystem types; \(E_{jr}\) is the unit price of service of \(j\) ecosystem types nationwide.
2.4. Method of calculating service function of Cropland ecosystem in grain production

To determine the service function of grain production per unit area of Cropland (Xiaoyu et al., 2003):

\[
E_a = \frac{1}{7} \sum_{i=1}^{n} \frac{m_i p_i q_i}{M} \quad (i=1, \ldots, n)
\]  

Where, \(E_a\) is the grain-production economic value per unit area of Cropland ecosystem (yuan hm\(^{-2}\)); \(i\) is crop variety; the main crop varieties in the Tarim River Main stream area covers wheat, corn, sorghum, barley, beans and peas, oil crops and sugar beet; \(p_i\) is the average price of \(i\) crop nationwide (yuan hm\(^{-2}\)); \(q_i\) is the yield of per unit area of \(i\) crops (t hm\(^{-2}\)); \(m_i\) is the area of \(i\) crop (hm\(^2\)); \(M\) is the gross area of \(i\) grain crop (hm\(^2\)). 1/7 means that the economic value provided by the natural ecosystem without manpower investment is 1/7 of the grain-production economic value by current unit area of Cropland.

2.5. Conversion method of invariant economic value

\[
V_n = V_m \times \frac{\Phi_m}{\Phi_n} \times 100\%
\]

Where, \(V_n\) is the invariant economic value during the research period (calculating at constant price during the base period); \(V_m\) the present-year’s price of the economic value during the research period; \(\Phi\) the inflation index of each year; \(m\) the research period; \(n\) the base period.

2.6. Calculation of quantity of unit service value for the ecosystem of the river basin

Determination of economic value of ecological service per unit area for the ecosystem of the river basin ecosystem: based on “Equivalent Factor Table of Chinese Ecosystem Service Value” and the economic value of grain production service per unit area of the cropland ecosystem in the region investigated, the unit price of other ecosystems or other ecological service functions in this region can be obtained (Xiaoyu et al., 2003).

\[
E_{ij} = e_{ij} E_a \quad (i=1, 2, \ldots, 9; j=1, 2, \ldots, 5)
\]

Where, \(E_{ij}\) is the unit price of \(i\) ecological service functions of \(j\) ecosystem types; \(e_{ij}\) is the equivalent factor of \(i\) ecological service functions of \(j\) ecosystem types to the unit price of grain production service provided by cropland ecosystem; \(i\) is the type of ecosystem service function; \(j\) is ecosystem types including forest, grassland, cropland, wetland and unused land ecosystems.

2.7. Calculation of regional ecosystem’s service value

\[
V = \sum_{i=1}^{9} \sum_{j=1}^{5} A_j E_{ij} \quad (i=1, 2, \ldots, 9; j=1, 2, \ldots, 5)
\]

Where, \(V\) is the total value of regional ecosystem service; \(A_j\) is the area of \(j\) ecosystem type; \(E_{ij}\) is the unit price of \(i\) ecological service type of \(j\) ecosystem type; \(i\) is the type of ecosystem service function; \(j\) is ecosystem type.
3. Result and Analysis

3.1. Calculation of unit price of ecosystem service function

According to Xinjiang Statistical Yearbook and Statistical Yearbook of Xinjiang Production & Construction Corps, the quantity of unit value of cropland ecosystem grain production during 1973~2005 is calculated. In order to highlight the comparability of five-period data during 1973~2005, the annual unit price of grain production value of cropland ecosystem is calculated based on the constant price of 1990 and the index of grain purchase with elimination of inflation factor, which respectively are 217.39 yuan, 216.02 yuan, 289.18 yuan, 1042.63 yuan, and 1157.95 yuan.

The quantity of unit value of the service function of various ecosystem types within the trunk stream area of Tarim River during 1973-2005 (Table 2) is calculated and obtained in a same way. The quantity of unit value shows an increase trend as a whole in this area during 1973-1983, which increases from 0.19×10^9 yuan in 1973 to 1.05×10^9 yuan in 2005. In 1983, however, the grain production capacity of cropland ecosystem decrease slightly due to the implementation of policy of state monopoly for the purchase and marketing of grain and domestic political environments.

Table 2 Unit Price of Service Function of Grassland (G) and Cropland(C) Ecosystems within Main Stream Area of Tarim River during 1973-2005 (Constant Price in 1990) (Yuan)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>173.92</td>
<td>108.70</td>
<td>108.01</td>
<td>231.34</td>
<td>144.59</td>
</tr>
<tr>
<td>B</td>
<td>195.66</td>
<td>193.48</td>
<td>192.26</td>
<td>260.26</td>
<td>257.37</td>
</tr>
<tr>
<td>C</td>
<td>173.92</td>
<td>130.44</td>
<td>129.61</td>
<td>231.34</td>
<td>173.51</td>
</tr>
<tr>
<td>D</td>
<td>423.92</td>
<td>317.40</td>
<td>315.39</td>
<td>563.90</td>
<td>422.20</td>
</tr>
<tr>
<td>E</td>
<td>284.79</td>
<td>356.53</td>
<td>282.99</td>
<td>354.28</td>
<td>378.82</td>
</tr>
<tr>
<td>F</td>
<td>236.96</td>
<td>154.35</td>
<td>235.47</td>
<td>153.38</td>
<td>205.32</td>
</tr>
<tr>
<td>G</td>
<td>65.22</td>
<td>217.39</td>
<td>64.81</td>
<td>216.02</td>
<td>86.75</td>
</tr>
<tr>
<td>H</td>
<td>10.87</td>
<td>21.74</td>
<td>10.80</td>
<td>21.60</td>
<td>14.46</td>
</tr>
<tr>
<td>I</td>
<td>8.70</td>
<td>2.17</td>
<td>8.64</td>
<td>2.16</td>
<td>11.57</td>
</tr>
</tbody>
</table>

Note: A: Gas regulation B: Climatic regulation C: Water-source conservation D: Formation and protection of soil E: Waste disposal F: Biodiversity protection G: Grain production H: Raw material I: Amusement activities

3.2. Economic value of cropland and grassland ecosystem service function and its change

3.2.1 Change in area of cropland and grassland ecosystem service function and its change

During those 32 years from 1973 to 2005, a remarkable change in the areas of various ecosystem types is seen (Fig.2) with an overall dynamic rate up to 272.76%. In terms of tendency, an increasing trend is found in the areas of cropland land. Compared to those of 1973, the areas of cropland land in 2005 are found to have increased by 186.15% while a decrease trend is found in the areas of grassland with a respective percentage of 4.53%. The detailed analysis shows that the change in ecosystem types
could be divided into three stages based on its rate and trend: the most remarkable change in ecosystem types took place during 1973-1983 and the dynamic degree of the change in each ecosystem type totals to 107.89%; the change during 2000-2005 comes next with total dynamic degree up to 68.29%; and the change during 1983-2000 is relatively mild with total dynamic degree of 56.31%. Both the rate and trend of change are characteristic of a “U” shape.

The analysis of change in the area of different type of ecosystem indicates that all the foresaid three stages of cropland ecosystem are of increase trend with an increment more than 30%, among which, the increment during 2000-2005 is the most remarkable one and up to 57.63%. The area of cropland increases by 38.46% during 1973-1983. In the middle of 1990s, the ecological environment was deteriorating in the trunk stream area of Tarim River. The area of grassland is still of a trend of decrease.

3.2.2 Change in value of ecosystem service function

According to the internal structural changes of service function value of various ecosystem types in the Main stream area of Tarim River, it is indicated that grassland ecosystem service function value have a change trend the same as the general change trend with a U-curve in change rate except the continuous increase in the service function value of cropland ecosystem.

The area of each ecosystem type in the trunk stream area of Tarim River during 1973-2005 and its corresponding unit price of service are analyzed. It is shown that in the region investigated, the service function value of ecosystem increases as a whole, which increases from $9.44 \times 10^9$ yuan/year in 1973 to $40.69 \times 10^9$ yuan/year in 2005 by more than 4 times. A straight-line model can be used to describe the change trend of service function value of the ecosystem in this area along with time ($Y=90844x-636320$ ($R^2=0.79$)). There is also, however, a period of decrease partially. The service function value of the ecosystem in the trunk stream area of Tarim River decreased by 16.02% during 1973-1983, and the mean decrease is $0.15 \times 10^9$ yuan per year. The service function value of the ecosystem in this area has been increasing continuously since 1983 with an average rate of annual increase of 13.56%. In particular, the maximum increment during 1990-2000 is up to 258.54%.

3.3. Research of the sustainable development of Tarim River

The ecosystem service function value in the trunk stream area of Tarim River is reflected with an integral increase on one hand, and on the other hand, also is manifested with the internal transfer of value. During 1973~1983, the service function values of grassland ecosystems decrease by $1 \times 10^9$ yuan while that of cropland ecosystem ecosystem increases by $80 \times 10^6$ yuan. During 1983-2005, the service function values of grassland and cropland land ecosystems increase respectively by $2.87 \times 10^9$ yuan and $12.35 \times 10^9$ yuan, of which, cropland ecosystem has the most remarkable increment up to 1007.8%, and the
increments of service function value with respect to grassland ecosystems are analogous. The service function of grassland ecosystems also shows an increase trend as a whole because the service function values provided by the unit area of those ecosystems are higher than that of other ecosystems, and the biomass produced by cropland ecosystem changes somewhat due to the improvement of economic development level, which causes that even the ecosystem area decreases as a whole, the service function value of those ecosystems increases all the same.

The level of human community and economic development is reflected to some extent by the development of cropland ecosystem service function. In contrast to agricultural ecosystem, the service function value of other ecosystems reflects the integral capacity of the ecosystem, which is opposite to the capacity of anthropic production and service. During 1973-2005, the ratios of the respective service function values of grassland ecosystems to that of cropland ecosystem were decreasing, which reduced respectively from 14.6% in 1973 to 4.8% in 2005. It indicates that the increase rate of the service function value of grassland ecosystems is much lower than that of cropland ecosystem. In the context of the development of human community, the value of those ecosystems is in a constant decreasing state, and the capacity of providing service is also decreasing continuously, which brings a severe negative impact on the integral balance of the ecosystem.

4. Conclusion and Discussion:

Tarim River trunk stream flows around the north edge and the west part of Taklimakan Desert, which is the typical percent. The ecosystem types along the river cover forest, grassland, wetland, cropland and unused land with typical characteristic of endorheic river ecosystem in arid area. This region features resources advantage and fragile environmental background, and the ecosystem is threatened by a synergistic impact of multiple environmental factors and intensive anthropic interference, which is the reason why it is selected for the research on the economic value of ecosystem service function and its change. On one hand, the research is intended to provide data for evaluating the scarcity of various ecosystems in arid area; on the other hand, the research is intended to help understand the process and characteristics of change in ecosystem service function value of this region, revealing the driving factors for the change in various ecosystems’ service value. By this means, the researcher hopes to provide a theoretical foundation for exploring the control strategy of ecosystem service function value in this region, the ecological safety of arid-area endorheic river as well as the sustainable development of society and economy.

(1) With the impact of inflation factor excluded and based on the grain production of cropland ecosystem, the calculated result of quantity of unit value of the service function of each ecosystem shows that the actual value of quantity of unit value of service function of Tarim River trunk stream ecosystem has increased in a whole. Although the quantity of unit value declined slightly by 0.63% during 1973~1983, yet it increased by 432.65% during 1973~2005.

(2) It is shown by the analysis of change in the area of land-use type in the trunk stream area of Tarim River during 1973~2005 that the areas of cropland land in this region increase by 186.2%; the areas of grassland drop relatively great as a whole by 4.53%, and the regional ecological environment is of a degradation trend as a whole.

(3) It is shown by the analysis of change in the economic value of the ecosystem service function in the trunk stream area of Tarim River during 1973~2005 that the economic value of the ecosystem service function in the region investigated is of an increase trend, and the economic value increases from $9.44 \times 10^7$ yuan/a in 1973 to $40.69 \times 10^9$ yuan/a in 2005 by more than 4 times, which reflects to some extent that the importance of ecosystem service function to the development of human community increases. On the other hand, the service function value of the ecosystem in this region transfers within the internal
structure, namely, a great amount of economic value of the service function of grassland ecosystems transfer into the cropland ecosystem. The increment per unit area of cropland ecosystem is superposed on the quantity of unit value that rises increasingly and leads to an increasing growth of the economic value of the cropland ecosystem service function during those 32 years. It is indicated with data that the value of cropland ecosystem service function increases by $2.95 \times 10^9$ yuan; the economic value of grassland ecosystems’ service function, however, increased far slower than that of cropland ecosystem did, in other words, the former is in a state of relative decrease, and the capacity and contribution provided by grassland ecosystems decrease continuously in an integral ecosystem, thus the integrative capacity and integral equilibrium of the ecosystem is effected severely.

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