RS-BASED LANDSCAPE DYNAMIC EVOLUTION IN AREAS OF CASCADE HYDROPOWER STATION CONSTRUCTION IN THE UPPER YELLOW RIVER

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ABSTRACT:

With the increasing demand for energy sources, a further development hydropower energy resource will be an inevitable choice for China's resource strategy. The cascade hydropower station construction produced serious impacts on the regional eco-environment. The most obvious characteristics of impacts caused by the cascade hydropower plant development are progressive, cumulative and regional, which can be described more clearly after applying remote sensing technology on its perspective of space-time. In this paper, the study of Yellow river section between longyangxia to Liujiaxia reservoir locates in the northwest inland plateau of China. The remote sensing data of 1977, 1996, 2000 and 2006 were selected to analyze regional landscape pattern evolution for hydropower cascade developments in last 30 years. The result indicates that the quality of regional ecosystem has been deteriorating since the1970s. The grass area has dropped from 8851.61 km^2 in 1977 to 8228.86 km^2 in 2006, in addition, the whole water area including rivers, reservoirs and bottomlands has expanded from 470.48 km^2 in 1977 to 703.55 km^2 in 2006. According to reviews of the regional landscape evolution, the Contagion Index presents a declining trend while the landscape diversity indexes rise, which implies that regional landscape patches turn to be more fragmented. The Landscape Shape Index of grass has increased from 40.07 in 1977 to 81.71 in 2006. This research demonstrates that regional land cover structures and landscape patches are evidently influenced by cascade hydropower exploitation. The remote sensing imagery information by Landsat series has been proved to be an effective means to manage and monitor the regional environment.

1. INTRODUCTION

With the increasing demand for energy sources as a result of rapid economic development, a further development hydropower energy resource will be an inevitable choice for China's resource strategy (Zhe-Ren Dong, 2006). The Yellow River which rises on the northern slopes of the Bayankela Mountains of Qinghai province is one of the most significant areas for hydropower development. The river falls 4450 m over a length of 5464 km, draining a basin area of 752443 km^2. The total quantities of exploitable hydropower resources are 3421.6×10^4 kw and the annual electricity generating capacity reaches 1253×10^8 kw•h in the main stream of Yellow River. Thus, the Yellow River has natural advantage of hydropower resources (Zhen-ke Zhang, 2004). According to the planning of the upper Yellow River hydropower development corporation, a series of large-scale hydropower stations have been constructed and the layout of continued hydropower construction includes about 39 hydropower stations. The multi-level stations construction, ranging from Longyangxia hydropower station to Liujiaxia hydropower station, is the most intensively river gorges project, which concentrated 10 hydropower stations. But the natural ecological environment is fragile as grassland degradation and desertification intensified in the upper reaches of Yellow River. As a double-edged sword, the regional hydro-power exploitation will promote the development of local economy; meanwhile, it may ruin the ecosystem and the environmental quality.

The regional ecological impacts occurred as the consequence or concomitant of cascade hydropower plant construction are quite obvious, which is one of the very problems caused worldwide concern recently. In the process of the hydropower station construction, reservoir inundation, land for project and construction use, the construction of migration areas and other facilities, all of which rapidly altered the regional land cover and landscape pattern, and produced serious impacts on the regional eco-environment. Furthermore, even a minor change of water-level in a small dam may cause a major consequence on regional landscape patterns (M. Matete, 2006). Generally, the construction of reservoir not only dramatically increases the water area in the near region, but also promotes the local economic development. Under the disturbance, the regional biodiversity, various ecological processes and edge effect are affected, which were the key index to assess the landscape quality (O.Bender, H.J.Boehmer, ea al. 2005).

The most obvious characteristics of impacts caused by the cascade hydropower plant development are progressive, cumulative and regional (Anna Brismar. 2004), which can be described more clearly after applying remote sensing technology whose advantage lies on its perspective of space-time. By using remote sensing technology, images from satellite-based instruments are effective on collecting high spatial, spectral, and temporal resolution information related to watershed environment. The Landsat series of sensors are the most popular ones in collecting regional environmental data for comparison analysis (W. Ouyang, 2007; F.H. Hao, 2007). The

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Multi-spectral Scanner (MSS), Thematic Mapper (TM) and Enhanced Thematic Mapper Plus (ETM+) sensor series can provide continuous high spatial resolution images. Since 1972, plenty of such images captured by Landsat series of sensors have been used in the retrospective assessment of the regional environmental quality (W. Ouyang, 2007). Now, remote sensing is an effective way for regional construction disturbance observations. At present, there is no such case study that systematically analyzes regional ecological impacts by the development of cascade hydropower stations in large rivers. Thus, applying remote sensing techniques to the study makes this thesis innovative. The goal of this paper is to assess the dynamic evolution of landscape pattern in areas of cascade hydropower station construction in the upper Yellow River by Landsat series data.

2. METHODOLOGY

2.1 Study area sites and data

In this paper, the study of Yellow river section between longyangxia to Liujiaxia reservoir reaches to 425 km long (including Longyangxia Reservoir 105 km). This area locates in the northwest inland plateau of China, east edge of northeastern Qinghai-Tibet Plateau, acrossing Qinghai and Gansu provinces (Figure 1).This region is typical continental climate with plateau natural condition. The coldest and warmest average monthly temperature is 0-0.5°C in January and 15-15.5°C in July. Mean annual precipitation ranges from 194 to 357 mm, most occurs between June and August. However, the mean annual pan-evaporation is between 1500 and 2131 mm, exceeding precipitation nearly up to 10 times. The study area is the upper region of Yellow River watershed, which average altitude is 2800-4800 m above sea level with a sharp eastward gradient. The Yellow River watershed is characterized by both rich natural resources and fragile eco-environments.

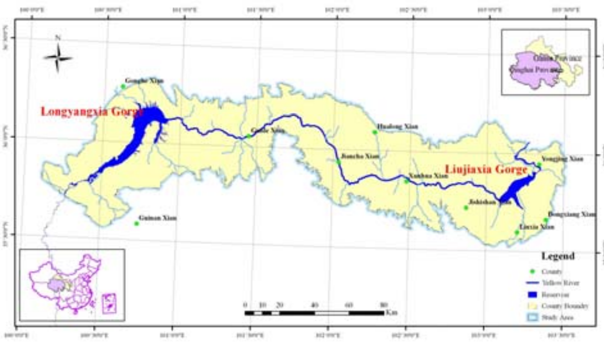

Figure 1 The location of the study area

2.2 Images interpretation and landscape classification

Basing on the field survey, people classified image data provided by MSS (1977), TM (1996, 2006), and ETM+ (2000), analyzed the quantity, the inner structure as well as the space distribution of land use for hydropower cascade developments in last 30 years.

For the image analysis, we selected the most cloud-free image available from approximate period in study area. The selected image (Path 131-133, Row 35) was dated on August and was orthorectified and projected to Universal Transverse Mercator (UTM) Zone 47N. The images were resized by the assessment boundary using the ENVI 4.3 software and then local landscape information was concluded out by Arc GIS 9.1.

Accurate image classification is a base for an accurate analysis and interpretation of satellite data (W. Ouyang, 2007). The image was opened in ENVI Imagine, using band combination for supervised classification. Image classification parameters were set to non-parametric rule — parallelepiped, overlap rule — parametric, unclassified rule — parametric and parametric rule — maximum likelihood (Rahul and Jennifer, 2007). Vegetation classification was done with reference to field investigation data. The field visits were used to identify valid training sites. For each land cover type, 5-10 regions of interest (ROIs) were selected in the signature editor. A supervised signature extraction with the maximum likelihood algorithm was employed to classify the Landsat images. And the land cover classification consists of water area, farmland, woodland, low coverage grassland, middling coverage grassland, high coverage grassland, construction land and unused land (Figure 2).

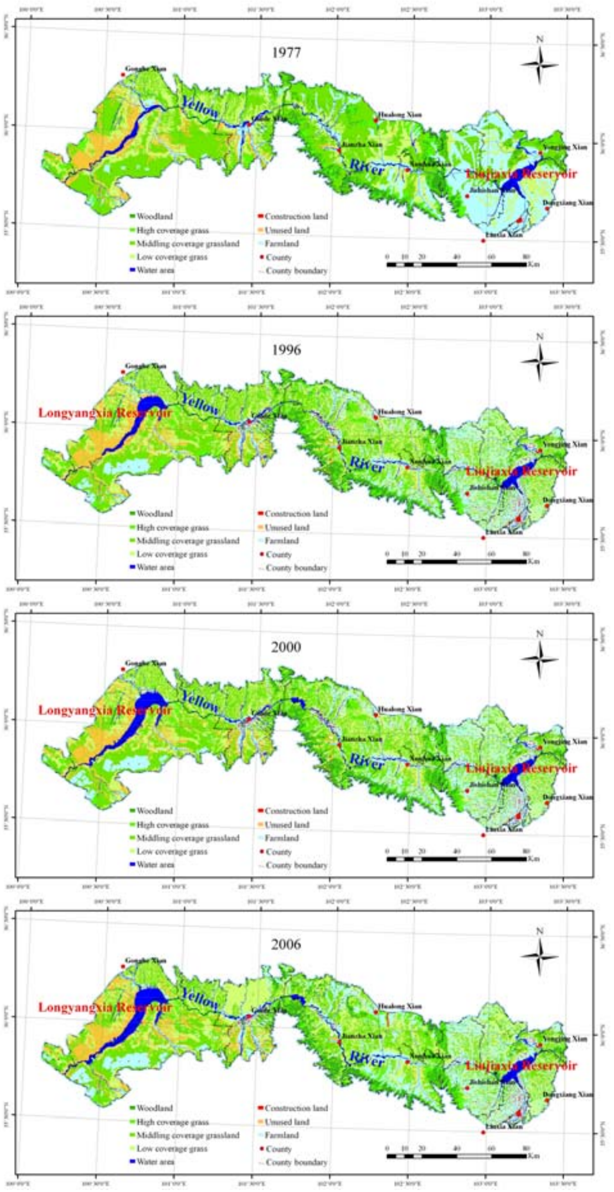

Figure 2 Landscape dynamic evolution in study area from 1977 to 2006

3. RESULTS AND DISCUSSIONS

3.1 Landscape dynamic evolution in study areas

Based on the landscape classification, the landscape dynamic change information can be concluded by the ArcGIS 9.1 software. The individual class area and change statistics for the 30 years are summarized in Table 1. It showed that grassland was the dominant landscape type. Area of grassland in different coverage was 8228.86 km^2 in 2006, a ratio of 59.33%. The main green plantations in this region were the grassland. However, the water area and construction land only took a small part in this region in the last 30 years.

The construction of dam increases the water area in the region around reservoir. And the grassland has turned out to be water area for reservoir inundation. The grassland area has dropped from 8851.61 km^2 of total area in 1977 to 8228.86 km^2 in 2006 with a decrease of 7.04%. In addition, there had been some opposite changes in it. The thirty years from 1997 to 2006 witnessed the obvious drop of the middling coverage grassland from 4960 km^2 to 3676 km^2 with the ratio of it decreased from 35.76% to 26.50%; the area of low coverage grass experienced a steady increase in amount from 3149 km^2 in 1977 to 3843 km^2 in 2006 with the ration of it increased from 22.71% to 27.71%; the high coverage grass area decreased slightly during the past thirty years. The area of woodland ascended from 793 km^2 to 901 km^2, with a 0.8% rise, for the woodland is far away from the water area, it can be concluded that the impact of the construction of the hydropower station to the woodland is slight and acceptable. For the newly constructed reservoir, the whole water area including rivers, reservoirs and bottomlands has expanded from 470.48 km^2 in 1977 to 703.55 km^2 in 2006 with the ratio of water area increased from 3.39% to 5.07%. The construction of cascade hydropower station also accelerated local economic development, which converted most unused land to construction land. The change in farmland area was minimal, with a small increase from 2706 km^2 in 1977 to 2775 km^2 in 2006. The regional landscape structure was changing notably with a massive increase of water area. These data proved that the main influence area of cascade hydropower reservoir to ecological landscape was the surrounding region in the last 30 years.

Year / Landscape type	1977		1996		2000		2006	
	Area(km^2)	Ratio(%)	Area(km^2)	Ratio(%)	Area(km^2)	Ratio(%)	Area(km^2)	Ratio(%)
Woodland	793.65	5.72	829.28	5.98	822.71	5.93	901.20	6.50
Low coverage grass	3149.20	22.71	3572.22	25.76	3601.61	25.97	3843.52	27.71
Middling coverage grass	4960.11	35.76	4407.32	31.78	4294.05	30.96	3675.92	26.50
High coverage grass	742.30	5.35	678.12	4.89	636.98	4.59	709.42	5.12
Water area	470.48	3.39	522.82	3.77	650.05	4.69	703.55	5.07
Construction land	12.26	0.09	150.45	1.08	152.56	1.10	156.04	1.13
Unused land	1035.16	7.46	1099.59	7.93	1037.46	7.48	1104.26	7.96
Farmland	2706.14	19.51	2609.52	18.82	2673.87	19.28	2775.40	20.01
Total	13869.3	100	13869.3	100	13869.3	100	13869.3	100

Table 1 Statistics of landscape change in the study area from 1977 to 2006

3.2 Regional landscape pattern trajectory analysis

Landscape structure could be described by its composition and configuration. Landscape composition refers to characteristics associated with presence and amount of each patch type within the research boundary. Landscape element is the basic, relatively homogenous and ecological units. So, it is feasible and reasonable to assess landscape variation by the patch related index. The most important landscape element type is the patch, which is a nonlinear surface area differing in appearance from its surroundings (W. Ouyang, 2007).

Besides analyzing rules of the landscape structure change from 1977 to 2006, the paper also studies the spatial-temporal characteristics in landscape evolution during the past 30 years grounded on 10 landscapes indexes by using geographic information system (GIS) and the landscape analysis tool FRAGSTATS.

- Patch density (PD)

$$PD = \frac{n_i}{A} \quad (1)$$

Where A = total landscape area (m^2)
n_i = number of patches in the landscape of class type i.

- Mean patch size (MPS)

$$MPS = \frac{\sum_{j=1}^{n} a_{ij}}{n_i} \quad (2)$$

Where a_{ij} = patch area
n_i = the patch number of different land use.

- Largest patch index (LPI)

$$LPI = \frac{\max_{j=1}^{n}(a_{ij})}{A} \quad (3)$$

Where a_{ij} = patch area
A = the total area of all patches.

- Landscape shape index (LSI)

$$LSI = \frac{0.25E}{\sqrt{A}} \quad (4)$$

where E = length of total patches borderlines.
A = the total area of all patches.

- Edge density (ED)

$$ED = \frac{1}{A}\sum_{i=1}^{m}\sum_{j=1}^{m} p_{ij} \quad (j\neq 1) \quad (5)$$

Where m = total landscape factor types at certain special resolution
P_{ij} = total length of borderline that shared by two consecutive landscape patches (patch i and patch j).

- CONTAG

$$CONTAG = \left[1 + \frac{\sum_{i=1}^{m}\sum_{k=1}^{m}\left[(P_i)\frac{g_{ik}}{\sum_{k=1}^{m} g_{ik}}\right]\bullet\left[(\ln P_i)\frac{g_{ik}}{\sum_{k=1}^{m} g_{ik}}\right]}{2\ln m}\right] / 100 \quad (6)$$

Where m = number of patch types (classes)
Pi = proportion of the landscape occupied by patch type (class) i,
g_{ik} = number of adjacencies (joins) between pixels of patch types (classes) i and k.

- Shannon diversity index (SHDI)

$$SHDI = \sum_{i=1}^{m}\left(p_i \times Lnp_i\right) \quad (7)$$

Where Pi = proportion of the landscape occupied by patch type (class) i.

- Modified Simpson's diversity index (MSIDI)

$$MSIDI = -\ln \sum_{i=1}^{m} P_i^2 \quad (8)$$

Where Pi = proportion of the landscape occupied by patch type (class) i.

- Shannon evenness index (SHEI)

$$SHEI = -\frac{\sum_{i=1}^{m} p_i \times Lnp_i}{Lnm} \quad (9)$$

Where Pi = proportion of the landscape occupied by patch type (class i)
m is number of patch types (classes).

- Modified Simpson's evenness index (MSIEI)

$$MSIEI = \frac{-\ln \sum_{i=1}^{m} P_i^2}{\ln m} \quad (10)$$

Where Pi = proportion of the landscape occupied by patch type (class i)
m is number of patch types (classes)

Landscape index	year	Grass land	Farmland	Construction land	Woodland	Water land	Unused land	Landscape
PD	1977	0.0604	0.0171	0.0024	0.0491	0.0036	0.0412	0.1738
	1996	0.0751	0.1134	0.1073	0.0598	0.0041	0.0551	0.4148
	2000	0.0765	0.1148	0.0994	0.0596	0.0037	0.0591	0.413
	2006	0.0949	0.1013	0.0662	0.0635	0.0107	0.0675	0.404
MPS	1977	1032.3618	1224.1253	36.0503	116.5965	968.9796	181.0381	575.4012
	1996	830.9357	166.1222	10.3887	99.7627	917.0495	143.7226	241.0636
	2000	812.8416	165.1289	10.3396	99.3936	1274.8394	121.988	242.113
	2006	624.8233	201.6722	11.4228	102.2128	475.3234	117.8512	247.5038
ED	1977	9.9399	3.8337	0.057	3.5426	1.8848	3.7504	11.5042
	1996	20.9804	14.295	1.6763	4.9309	2.1573	5.0372	24.5386
	2000	21.0998	14.1118	1.532	4.8889	2.2434	5.0225	24.4492
	2006	19.9437	12.6308	1.0374	4.581	2.1944	5.0391	22.7132
LSI	1977	40.0701	25.5219	5.7009	47.521	29.7752	41.1095	37.7611
	1996	79.1217	97.8841	46.8301	63.0677	32.7915	53.5884	76.1448
	2000	81.1646	96.3921	44.5822	62.8039	30.5859	56.0493	75.9063
	2006	81.7104	83.3806	35.2884	56.7011	28.7456	53.4477	70.7972
LPI	1977	34.8372	6.6973	0.0418	0.6008	1.2417	1.9997	34.8372
	1996	9.1917	2.6185	0.0593	0.4186	1.9565	2.6494	9.1917
	2000	11.4713	2.0707	0.0559	0.417	3.2208	1.8083	11.4713
	2006	16.9765	2.0745	0.0557	0.9659	2.6392	2.604	16.9765

Table 2 Landscape pattern index in areas of cascade hydropower station construction

The computed results of those indices are listed in Table 2. For the construction of cascade hydropower station, the original natural ecosystem was affected. The patch density of the grassland, farmland, woodland, water area and unused land increased steadily while the mean patch size decreased correspondingly, which accounted for fragmentation of these landscape types. The PD of the construction land dropped in the last ten years while the MPS went up recently, which indicated the ascending trend of connectivity and integrity of construction land. The Largest Patch Index (LPI) of water area has climbed rapidly, but as for the Mean Patch Size (MPS) of grassland, it has shown a decreasing tread, it can be explained that as the grassland patches were extensively distributed in the landscape around the water area, the rising of the water level because of the construction of the cascade hydropower station contributed to the fragmentation of the grassland. The LPI provided the information about the role the largest patch played in the total patches of the same land use. For the landscape change, the LPI of the water area, construction land, woodland and unused land climbed. The calculated LSI in the table did not fluctuate obviously, which suggested the reservoir construction did not change the patch shape intensively.

Year	CONTAG	SHDI	MSIDI	SHEI	MSIEI
1977	66.4342	1.1025	0.8157	0.6153	0.4553
1996	62.623	1.1515	0.8298	0.6427	0.4631
2000	62.4593	1.158	0.8351	0.6463	0.4661
2006	61.5337	1.2013	0.9001	0.6705	0.5024

Table 3 Index comparisons of landscape diversity structure

According to reviews of the regional landscape evolution, the Contagion Index (CONTAG) presents a declining trend while the landscape diversity indexes such as Shannon's Diversity Index (SHDI) rises, which implies that regional landscape patches turn to be more fragmented and the landscape had a trend of diversity and regularity surrounding the hydropower station field. The increased SHDI meant the diversity degree of each land use climbed up and centralized. The calculation of the

MSDI and MSEI proved the patch of different land use scattered quite evenly. The SHEI increased steadily, which indicated that the reservoir construction caused kinds of more even landscape in the region. The indices drew from the table did not fluctuate significantly proved that the regional landscape structure and diversity were not changed essentially.

4. CONCLUSIONS

The result indicates that the quality of regional ecosystem has been deteriorating since the1970s. What's more, the land use transformation demonstrates that the grassland has turned out to be water area and unused land. This research demonstrates that regional landscape structure and landscape patch fragmentation are evidently influenced by cascade hydropower exploitation. The continuing cascade hydropower (station) development does impact functions and the stability of regional ecosystem in the upper Yellow River. The remote sensing imagery information by Landsat series has been proved to be an effective means to manage and monitor the regional environment.

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