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Systematic Environmental Impact Assessment for Non-natural Reserve Areas: A Case Study of the Chaishitan Water Conservancy Project on Land Use and Plant Diversity in Yunnan, China

*Zhi-Xin Zhu[1], Kun-Kun Zhao[1], Qin-Wen Lin[2], Salman Qureshi[3,4,5], Cynthia Ross Friedman[6], Guo-Yin Cai[7,8] and Hua-Feng Wang[1]**

[1] Hainan Key Laboratory for Sustainable Utilization of Tropical Bioresources, Institute of Tropical Agriculture and Forestry, Hainan University, Haikou, China, [2] Key Laboratory of Plant Resources and Beijing Botanical Garden, Institute of Botany, The Chinese Academy of Sciences, Beijing, China, [3] Department of Geography (Landscape Ecology), Humboldt University of Berlin, Berlin, Germany, [4] Integrative Research Institute on Transformations of Human-Environment Systems, Humboldt University of Berlin, Berlin, Germany, [5] School of Architecture, Birmingham City University, Birmingham, United Kingdom, [6] Department of Biological Sciences, Thompson Rivers University, Kamloops, BC, Canada, [7] Department of Remote Sensing Science and Technology, School of Geomatics and Urban Spatial Informatics, Beijing University of Civil Engineering and Architecture, Beijing, China, [8] Beijing Advanced Innovation Center for Future Urban Design, Beijing University of Civil Engineering and Architecture, Beijing, China

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***Correspondence:**
*Hua-Feng Wang
wanghuafeng2012@foxmail.com*

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Environmental impact assessment (EIA) before and after the establishment of a Water Conservancy Project (WCP) is of great theoretical and practical importance for assessing the effectiveness of ecological restoration efforts. WCPs rehabilitate flood-damaged areas or other regions hit by disasters by controlling and redistributing surface water and groundwater. Using Geographic Information System (GIS) and Composite Evaluation Index (CEI) in predictive modeling, we studied the degree to which a WCP could change land use, plant communities, and species diversity in Yunnan, China. Via modeling, we quantified likely landscape pattern changes and linked them to naturality (i.e., the percentage of secondary vegetation types), diversity, and stability together with the human interferences (e.g., conservation or restoration project) of an ecosystem. The value of each index was determined by the evaluation system, and the weight percentage was decided through Analytical Hierarchy Process (AHP). We found that minor land-use changes would occur after the Chaishitan WCP was theoretically established. The greatest decline was farmland (0.079%), followed by forest (0.066%), with the least decline in water bodies (0.020%). We found 1,076 vascular plant species (including subspecies, varieties and form) belonging to 165 families and 647 genera in Chaishitan irrigation area before the water conservancy establishment. The naturality and diversity decreased 11.18 and 10.16% respectively. The CEI was 0.92, which indicated that Chaishitan WCP will enhance local landscape heterogeneity, and it will not deteriorate local ecological quality. Our study proposes a comprehensive ecological evaluation system for this WCP and further suggests the importance of including the ecological and environmental consequences of the WCP, along with the well-established socioeconomic evaluation systems for non-natural reserve areas. We conclude that the Chaishitan WCP will have minor environmental impacts on the local landscape and plant diversity. Furthermore, the irrigation project will provide sufficient water once established, which will enrich local plant diversity; therefore, we support its construction.

Keywords: modeling, water conservancy project, landscape index, plant diversity, ecological evaluation

INTRODUCTION

Paradigm shifts in water conservation projects toward harmonizing the needs for humans and nature are essential (Liu et al., 2013). Researchers have been paying increasing attention to the socioeconomic impacts of water conservancy projects (WCPs), but their ecological and environmental consequences have received considerably less attention from the scientific community. WCPs rehabilitate flood-damaged areas or other regions hit by disasters by controlling and redistributing surface water and groundwater. In China, the Before-Project environmental impact assessment (EIA) system for major construction projects has been in place for more than 20 years (Chen et al., 2013). There is a standardized evaluation procedure for assessing the potential ecological effects of construction projects in operation, which involves conducting an on-site investigation and evaluation, making environmental impact predictions, and providing an EIA report. However, there is a general lag between the project's implementation and the assessment of its effects, because some construction projects are in the preliminary design phase, others are under construction, while still others have been completed, but they all need an EIA according to the current environmental management requirements. In other words, real-time ecological environment monitoring and evaluation research is scarce after the project's implementation, preventing assessment of the immediate consequences (Lu et al., 2003; Du and Wang, 2005; Chang et al., 2006; Zhang and Hu, 2010). In particular, quantitative assessments, whereby weights are given to the EIA quality indices according to their properties and importance, are lacking (Wang et al., 2003; Sun and Dong, 2004). Neglecting these ecological and environmental impacts may sometimes lead to unintended consequences (e.g., increasing the incidence of chronic diseases worldwide) for ecosystems as well as to declines in the critical ecosystem services provided to our society (Chen et al., 2013). Therefore, conducting field-based assessment for WCPs' ecological effects will facilitate WCP construction from an ecological perspective, and thus promote their sustainable development (Dong, 2003; Jiang, 2005). Furthermore, such research is of practical significance for EIAs of ecological restoration projects and of similar projects in future.

Previous studies have focused on the environmental and ecological impacts of specific projects; e.g., impacts of the Three Gorges Hydroelectric Project (TGHP) on ecological processes and biodiversity (Wu et al., 2003, 2004; Xie et al., 2003; Lopez-Pujol and Ren, 2009), environmental and ecological effects of the South-to-North Water Transfer Project (SNWTP) (Zhang, 2009). However, there are three shortcomings in the most recent EIA reports. Firstly, very little work has been conducted for non-rare, non-protected species or non-natural reserve areas, whereas biodiversity refers to a collection of all species. The loss of other common or unprotected species will cause declines in overall biodiversity (Chen et al., 2013). Secondly, there is a lack of an integrated vulnerability index based on independent landscape metrics and anthropic impacts. This kind of integrated index would be helpful for the planning of conservation and protection measures in protected areas (Černý et al., 2013; Nzeadibe et al., 2015; Caniani et al., 2016). Thirdly, while companies provide reliable quantitative information about their performance (Hammond and Miles, 2004), the industry has information gaps, as it fails to publicly communicate its level of environmental performance (Panwar et al., 2014; Mäkelä, 2017).

Furthermore, other studies, such as that by Steffen and Leuschner (2014) suggested that decade-long human impact on river hydraulics and chemistry can significantly reduce the community diversity at the landscape level, profoundly altering the relative abundance of the assemblages. Chen et al. (2013) also called for biological diversity impact assessments to be included in any EIA, generating a sound ecological protection and EIA system for established WCPs. Other researchers (e.g., Westman, 1985; Brismar, 2004) also suggested incorporating biological diversity effects into scope of the evaluation, i.e., to investigate the species abundance, distribution, endangered status, and existing problems resulting from the original protection measures. Determining whether it is necessary to protect biological diversity and take corresponding measures depends on local basic biological diversity characteristics and social economic status, which will enable evaluation of WCP scientifically and objectively.

The Chaishitan reservoir, a non-natural reserve area, is located at the interface of Yiliang and Shilin counties in Yunnan province, China (**Figure 1**). Recently, a water conservancy project has been planned for Chaishitan area to enable irrigation; i.e., Computer Aid Design (CAD) digital maps with the main and branch channels have been generated for implementation in 2016. Assessing land cover and plant diversity before project establishment will be invaluable because it would promote plants to flourish due to an increased water supply; such information would provide a baseline that would otherwise be absent once the water conservancy project became established. Therefore, in this study, we hypothesized that the local plant diversity will increase and that the land use will become more fragmented after the water conservancy project is established.

In this study, we conducted a comprehensive land use analysis and performed plant diversity sampling along the channel and the potential impact areas in Yunnan, China. We then investigated the land use and plant species after modeling the establishment of the Chaishitan WCP through a CAD

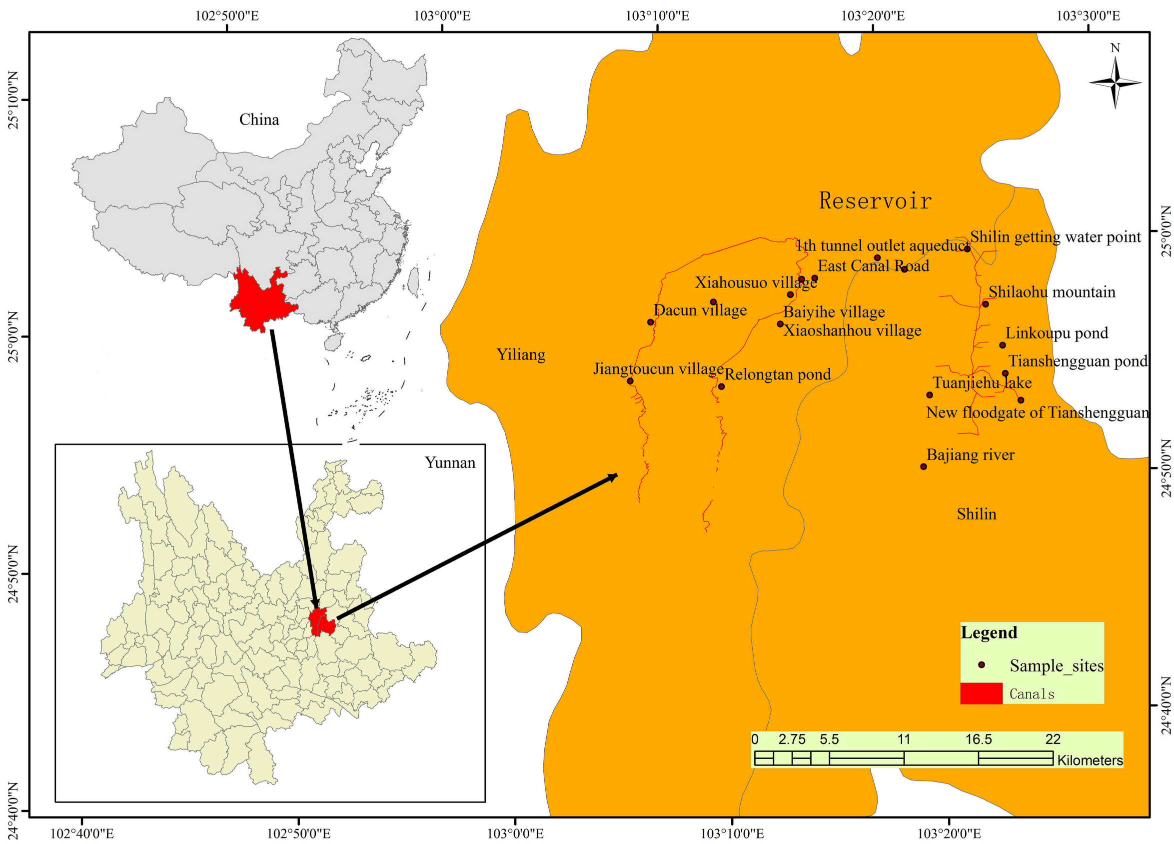

FIGURE 1 | The plant community sampling sites in Chaishitan water conservancy of Yunnan, China.

blueprint of the Chaishitan irrigation region. By comparing the landscape pattern index and plant species composition and relative abundance in the regions, we aimed to address the following questions: (1) How could land-use and plant diversity change immediately after the putative completion of the WCP? (2) Whether or not the Chaishitan WCP should be established in Yunnan as evaluated by our "before-and-after" systematic environment impact assessment; i.e., assessing the plant diversity and land use twice before and then after the project established.

METHODS

Study Area

The Chaishitan reservoir is one of the centerpieces of the Nanpanjiang River and is located upstream of the Zhujiang River (i.e., the Pearl River). The actual maximum water level of the Chaishitan reservoir is 1,643.74 m, and its corresponding capacity is of 0.381 billion m^3. However, Yiliang city and its surroundings often suffer severe drought. For example, in 2010, the drought areas of Yiliang county totaled 196.2 km^2, and 104 km^2 of croplands produced nothing due to drought at the end of that year (Anonymous, 2011). In addition, more than 100,000 people had difficulties in accessing safe drinking water because the vast majority of the surface rivers had dried up and the groundwater level had severely decreased in 2010. Therefore, it is urgent to establish an irrigation project (i.e., Chaishitan WCP) from the Chaishitan reservoir to meet the needs of surrounding Yiliang and Shilin counties.

Land Use and Remote Sensing Interpretation

Based on the Current Land Use Classification (GB/T 21010-2007) (CMDLRDC (Cadastral Management Division of Land and Resources Department of China) and LSPI (Lands Surveying and Planning Institute), 2007) issued by China's Land and Resource Ministry, we adopted Current Land Use Classification (**Table 1**). As the national standard, China's Land Use Status Classification is mandatory, principled and guiding; therefore, we adopted this unified standard in order to improve the level of land management and promote its application in Yiliang county of Yunnan province. Secondly, China's Land Use Status Classification conforms to China's national conditions; namely, it meets the relevant laws and regulations of China's domestic standards, which makes it easier for the construction project to obtain approval. Thirdly, we adopted the nationwide uniform standards, which facilitate the smooth development of the project's construction work; it will be easier to compare our results with similar projects in China and to provide reference for future related projects (Chen et al., 2013).

TABLE 1 | The land use area before and after Chaishitan water conservancy project establishment.

First land use types	Secondary land use types	Areas before project established (km^2)	Areas after project established (km^2)	Changed areas (km^2)	Percentage (%)
Urban and industrial land	Urban and industrial land	37.647	37.631	−0.016	−0.042
Farmland	Farmland	204.92	204.759	−0.161	−0.079
Orchard	Orchard	55.099	55.065	−0.033	−0.061
Forest land	Other kinds of forest land	16.924	16.91	−0.014	−0.085
	Forest land	156.756	156.651	−0.104	−0.066
Waters and water conservancy facilities Land	Water	15.64	15.637	−0.003	−0.02
	Water conservancy facilities Land		0.332	0.332	

The methods of remote sensing image interpretation are widely used and have been applied in previous studies (e.g., Qiu and Wang, 2010; Wang et al., 2013, 2016; Booth et al., 2016). The first-level classification was based on land use and land cover (LULC) characteristics, and the secondary classification is primarily based on the first survey characteristics of land management. One scene of Operational Land Imager (OLI) data from Landsat 8 was obtained in March 9, 2015 as the main source for the second survey of LULC classification. The spatial resolution of panchromatic and multispectral OLI was 15 and 30 m, respectively. Three main steps were taken for the classification. First, we performed a multi-resolution image segmentation to generate image objects to which the classification algorithm could be applied. For this segmentation, we used a "scale parameter" of 20, which was determined by visual interpretation of the segmentation results. The segmentation process identified objects that were homogeneous and included the features (i.e., spectral values, shape, texture, etc.) that can be used for classification (Walker and Blaschke, 2008; Qiu and Wang, 2010). Second, once the segmentation was achieved, we utilized a combination of fuzzy rules and a standard nearest neighbor (SNN) algorithm to classify each image object. A total of 200 training samples were selected and referenced with the auxiliary data (including digital topographic maps). We printed 20 images wherein land use or vegetation types could not be determined from the data alone, brought these images into the field, and either found the specific positions or asked the local people to identify the location. In total, 20 field surveys for the unidentified land use or vegetation types were conducted. Google Earth and local specific maps were also referenced in order to identify their representative classes. Based on the spectral and spatial information of these samples, we created the SNN feature space and fuzzy rule algorithms that were collectively used for classification. Each image object was assigned a probability of belonging to each LULC class, and the final class of image objects was decided on the basis of which assigned class has the highest probability. Finally, we refined the classification with manual adjustment to improve the overall quality of classification. The classification was performed using Definiens 7.0 software. Classification accuracy was assessed by comparing the reference collection with classified imagery (Congalton, 1991). Based on the derived LULC map, we further calculated the percentage for each LULC type in ArcGIS 9.3 (ESRI).

We overlaid the proposed CAD digital maps onto the above remote sensing image from Landsat 8, and then we interpreted the image again and predicted LULC changes immediately after the WCP has been built in 2016. Other ancillary data included 1:50,000 topographic maps, 1:250,000 land-use maps from 2014, district administrative maps and related land resources survey data, inventory reports and related maps.

Plant Diversity Sampling

The field survey on plant species structure and diversity adopted a previously used sampling protocol (Wang et al., 2011) to investigate the community composition and structure of typical vegetation in the region. The proposed layout of the Chaishitan WCP has one main-channel and two branch channels in Yiliang county, and one major main-channel and five branch channels in Shilin county. According to local people who are familiar with the proposed layout of Channels, we found the specific positions of the future channels passing away, and we set 21 plant diversity sampling plots along the channels or near the channels (**Figure 1**). Once the water conservancy established, most plant species will disappear because of habit loss, therefore, we get the plant diversity before the water conservancy established and predict how could plant diversity change based on the CAD maps and modeling (i.e., we assumed the plant species in or nearby proposed channels will disappear once the water conservancy established in 2016).

We performed plant diversity field investigations twice; the first time was conducted from May to June in 2015 for 27 days with seven people involved in the field work, and the second time was conducted from August to September in 2015 for 42 days with 11 people involved in the field work. We conducted field work according to different land use types: i.e., Secondary needle and broadleaf mixed forest (SF); Wasteland (Wetland) (WL); Eucalyptus plantation (EP); Orchard (OR), and Farmland (FL) (**Table 2**). The number of sampling sites with each kind of land use type varied from three to eight; eight sampling sites fell into Farmland. In total, 21 sampling sites were investigated (**Table 2**, Supplementary Material A). The plant diversity was investigated at three different layers; i.e., tree, shrub, and herb layers. At each sampling site, we investigated one 20 × 20 m tree plot: five 2 × 2 m shrub plots and five 1 × 1 m herb plots were surveyed within the tree plot at its four corners and center. In total, we had 21 tree plots, 105 shrub plots, and 105 herb plots. We recorded each

TABLE 2 | Plant community sampling sites in Chaishitan irrigation region, Yunnan province of China.

Code	Site	Land use types	Longitude	Latitude	Altitude (m)
1	Chaishitan Reservoir	Secondary needle and broadleaf mixed forest (SF)	103.34	24.99	1,721
2	1th tunnel outlet aqueduct	Farmland (corn) (FL)	103.32	25	1,640
3	East Canal Road	Orchard (chestnut) (OR)	103.27	24.99	1,681
4	Nuomizhuang village tube	Eucalyptus plantation (EP)	103.26	24.99	1,606
5	Xinjie	Eucalyptus plantation (EP)	103.26	24.01	1,616
6	Gengjiaying Canal inverted siphon	Farmland (rice) (FL)	103.23	24.04	1,589
7	The intersection of Jialonghe and road	Wasteland (Wetland) (WL)	103.23	24.04	1,563
8	Dacun village	Orchard (OR)	103.14	24.97	1,585
9	Jiangtoucun village	Wasteland (WL)	103.12	24.93	1,556
10	Relongtan pond	Eucalyptus plantation (EP)	103.19	24.92	1,594
11	Head of xihe river	Wasteland (WL)	103.19	24.98	1,563
12	Baiyihe village	Farmland (corn) (FL)	103.24	24.96	1,628
13	Xiaoshanhou village	Farmland (corn) (FL)	103.24	24.96	1,618
14	Xiahousuo village	Farmland (corn) (FL)	103.25	24.98	1,592
15	Shilin getting water point	Secondary needle and broadleaf mixed forest (SF)	103.39	25	1,840
16	Linkoupu pond	Orchard (apricot) (OR)	103.41	24.93	1,953
17	Tianshengguan pond	Farmland (tobacco) (FL)	103.41	24.91	1,923
18	New floodgate of Tianshengguan	Secondary needle and broadleaf mixed forest (SF)	103.42	24.89	1,927
19	Shilaohu mountain	Farmland (tobacco) (FL)	103.4	24.96	1,982
20	Tuanjiehu lake	Secondary needle and broadleaf mixed forest (SF)	103.35	24.9	1,864
21	Bajiang river	Farmland (corn) (FL)	103.34	24.85	1,814

species name, diameter at Breast Height (DBH) for trees, height, crown width, coverage for herb, and origin.

Data Analysis

Landscape Analysis

Vector graphics were converted into landscape classification grid maps using ArcInfo, and landscape indices were calculated with the Fragstats3.3 (McGarigal et al., 2015) at the landscape level. Patch density (PD), fractal dimension (FD), the clustered index (CONT), dominance index (LDI), degrees of separation index (SPLI), and Shannon diversity indices (SHDI), Number of Patches (NP), Edge Density (ED), Largest Patch Index (LPI), Percentage of Landscape (PLAND), Landscape Shape Index (LSI), Shape Index (Mean) (SHAPE_MN), and Fractal Dimension Index (FRAC_AM) were selected to quantify the modeled and predicted landscape pattern changes (see the concept of each index in **Table 3**). These landscape pattern indices were then linked to "naturality" (i.e., the percentage of secondary vegetation types), diversity, stability, and human interference in order to establish an evaluation system, which could then be used to estimate the ecological condition of the Chaishitan WCP immediately after its establishment in 2016.

In light of current ecological assessment systems (O'Neill et al., 1988; Zheng et al., 1994; Xia et al., 2005; Guo et al., 2007), naturality, diversity, stability, and threat of human interference were selected as assessment indicators (**Table 3**). The weight of each evaluation index was determined by an analytic hierarchy process (Yang and Xiao, 2000; Xu et al., 2002; Guo and Wang, 2005; Wan et al., 2005). Ecological assessment indicators with three levels were selected and evaluated from the perspective of ecological protection (**Tables 4A,B**).

A judgment matrix with three level ecological assessment indicators was established in a hierarchical way, which was gauged to reflect the relationship between the affecting factor and its perceived importance. More than 10 experts in the field of landscape or plant diversity assessment were invited to randomly respond to questionnaires "face-to-face" to determine the level of importance: equally important (1), slightly important (3), important (5), obviously important (7), and extremely important (9) (Xu et al., 2002; Wan et al., 2005; Guo et al., 2007). After experts determined the score, we established the judgment matrix and calculated the largest eigenvalue and eigenvector of the matrix as well as the weight of each index value. Regional comprehensive evaluation results are reflected by the following Composite Evaluation Index (CEI) formula (He et al., 2001; Guo and Wang, 2005):

$$CEI = \frac{1}{4}\sum_{i=1}^{n} C_i w_i$$

in which, C_i = the score of single evaluation index; w_i = the weights of the evaluation indices; n = the number of indices. The ecological environmental quality was assessed by the value of CEI according to Zheng et al. (1994).

We tested the random consistency index (CR) of the judgment matrix; if $CR \leq 0.1$, the matrix has a satisfactory consistency, and the weight (w) can be applied (He et al., 2001; Guo and Wang, 2005). The weight of naturality, diversity, stability and threat

TABLE 3 | Ecological assessment index used in this study.

Guide line layer	Target layer	Concept of index
Naturality	Percentage of vegetation type (Secondary needle- and broad-leaves mixed forest) (PV)	Percentage of vegetation type area and total area
Diversity	Shannon diversity index (SHDI)	Diversity index reflects the number of landscape type and its percentage
Stability	Landscape dominance Index (LDI)	LDI reflects the degree of little patch dominant in landscape
	Contagion Index (CONTAG)	CONTAG reflects spatial distribution of landscape type
	Landscape splitting Index (SPLIT)	Bigger splitting index reflects dispersed landscape type and worse stability
Threat of human interference	Human disturbance (HD)	Percentage of human interferential and natural landscape
	Perimeter-Area Fractal Dimension (PAFRAC)	PAFRAC reflects complexity of landscape shape, the value is between 1 and 2 (Qiu et al., 2007)
	Patch density (PD)	The number of patches of the corresponding patch type divided by total landscape area (m^2)

of human interference is 0.21, 0.15, 0.24, and 0.41 respectively (**Table 5**). In the target layer (see the definition in **Table 3**), the weight of each indicator is 0.33.

Plant Diversity Analysis Before Modeling

The arrangement order of the families is determined by Li (1996) and Wu (1991). Simpson, Shannon and Pielou indices were calculated to evaluate the diversity of trees, shrubs, and herb species in each sampling site. The indices were calculated as follows:

(1) The Simpson diversity index (*D*) (Simpson, 1949);

$$D = 1 - \sum_{i=1}^{S} P_i^2 \qquad P_i^2 = \frac{n_i(n_i-1)}{N(N-1)}$$

(2) The Shannon index (e-base) H'_e (Shannon, 1948);

$$H'_e = -\sum_{i-1}^{S} P_i \ln P_i$$

(3) The Pielou evenness index (*J*) (Pielou, 1966):

$$J_e = \frac{H'_e}{H'_{\max}}$$

In the formulae 1 through 3, $P_{\mathrm{i}} = n_i/N$, where n_i is the number of an individual species *I*, *N* is individual number of all species, while $H'_{\max}$ is the maximum Shannon index. If $D = 0$, there are no species in the plot.

SPSS (Statistical Product and Service Solutions) was used for statistical analyses to test the significance of differences, i.e., there is a significant difference between two variables if $p < 0.05$ (and not if $p > 0.05$).

RESULTS

Land Use and Landscape Pattern Changes before and after WCP Established

Land Use Changes

The total area of the WCP was 486,985 km^2, including Urban and industrial land, Farmland, Orchard, Forest land, and Waters/water conservancy facilities (**Table 1**). The land use did not change significantly once the WCP was established. Minor land use changes were detected before and immediately after the establishment of the Chaishitan WCP. The greatest decline was 0.079% for Farmland (0.161 km^2, the amount of the decreased area, similarly hereinafter), then 0.066% for Forestland (0.104 km^2). The least decreased is 0.020% (0.003 km^2) for water bodies (**Table 1**, **Figure 2**). The naturality and diversity decreased 11.18 and 10.16%, respectively. In the guide line layer (see the definitions in **Table 3**), a layer that includes naturality, diversity, stability, and threat of human interference (see **Tables 4A,B**). However, the threat of human interference index and ecosystem stability increased by 1.32 and 1.59%, respectively. The CEI decreased by 3.65% (**Tables 4A,B**).

Landscape Pattern Changes

The landscape changes after the WCP established were minor. The value of some landscape pattern indices decreased by about 10% while the value of other indices increased by about 3%. In the index layer (see **Tables 4A,B**), we found that Percentage of Vegetation type (PV), Shannon Diversity Index (SHDI), Perimeter-Area Fractal Dimension (PAFRAC) and Landscape dominance Index (LDI) decreased by 11.18, 10.16, 11.70, and 5.69%, respectively; however, we found that Patch density (PD), Contagion Index (CONTAG) and Landscape splitting Index (SPLIT) increased by 2.37, 0.75, and 8.66%, respectively (**Tables 4A,B**).

Class-level analysis indicates the structural characteristics for each land use type and can reveal the land use change features and trends. Eight class metrics; namely, NP, PD, ED, LPI, PLAND, LSI, SHAPE_MN, and FRAC_AM (see the abbreviations in the Methods) were selected to perform the land use type change analysis in this research and the statistical results are shown in **Table 6**, indicating changes in the landscape structure of each cover type.

Main Vegetation Types

Five kinds of main vegetation types were found in the field:

Secondary Broadleaf Forest (SF)

Secondary broadleaf forest is the main forest type commonly found in high altitudes; its dominant species includes *Pinus*

TABLE 4A | The landscape index and Composite evaluation index before Chaishitan water conservancy project establishment.

Guide line layer	Naturality	Diversity	Threat of human interference			Stability		
Weight	0.21	0.15		0.41			0.24	
Index	**Percentage of vegetation type (PV)**	**Shannon diversity index (SHDI)**	**Human disturbance (HD)**	**Patch density (PD)**	**Perimeter-Area Fractal Dimension (PAFRAC)**	**Contagion Index (CONTAG)**	**Landscape dominance Index (LDI)**	**Landscape splitting Index (SPLIT)**
Value	21.60	1.36	0.51	9.25	1.21	59.87	0.87	7.95
Standardization of value	1.76	0.07	0.00	0.73	0.06	4.96	0.03	0.62
				0.26			1.85	
Guide line layer	**Naturality**	**Diversity**	**Threat of human interference**	**Stability**				
Index value	1.76	0.07	0.26	1.85				
Weight	0.21	0.15	0.41	0.24				
Composite evaluation index (CEI)	0.92							

TABLE 4B | The landscape index and Composite evaluation index after Chaishitan water conservancy project establishment.

Guide line layer	Naturality	Diversity	Threat of human interference			Stability		
Weight	0.2079	0.1481		0.4065		0.2374		
Index	**Percentage of vegetation type (PV)**	**Shannon diversity index (SHDI)**	**Human disturbance (HD)**	**Patch density (PD)**	**Perimeter-Area Fractal Dimension (PAFRAC)**	**Contagion Index (CONTAG)**	**Landscape dominance Index (LDI)**	**Landscape splitting Index (SPLIT)**
Value	21.57	1.37	0.51	10.6	1.2	67.73	0.9	9.60
Standardization of value	1.566	0.064	0	0.75	0.05	5	0.03	0.68
				0.26			1.88	
Guide line layer	**Naturality**	**Diversity**	**Threat of human interference**	**Stability**				
Index value	1.57	0.06	0.26	1.88				
Weight	0.21	0.15	0.41	0.24				
Composite evaluation index (CEI)	0.89							

TABLE 5 | Determination of evaluation index weight of Chaishitan water conservancy project.

A	B1	B2	B3	B4	W_i
B1	1	2	1	1/3	0.21
B2	1/2	1	1	1/3	0.15
B3	1	1	1	1	0.24
B4	3	3	1	1	0.41

yunnanensis Franch., *Quercus variabilis* Bl. and *Cupressus duclouxiana* Hickel, *Cyclobalanopsis glauca* (Thunb.) Oerst., along with *Acer buergerianum* Miq (**Figure 3**).

Eucalyptus Plantations (EP)

Eucalyptus plantations [the main species is *Eucalyptus globulus* subsp. *maidenii* (F. Muell.) Kirkpatr.] were widely distributed in the roadside, hillside, dry land and farmland. Most of them are disjunct and distributed in small areas.

Farmland (FL)

Farmland mainly comprised dry areas growing corn, greenhouses containing common crops [such as *Panax notoginseng* (Burkill) F. H. Chen ex C. H. Chow, *Nicotiana tabacum* Linn.], and lowlands with good irrigation growing rice.

Orchards (OR)

There are a large number of orchards, including those growing *Castanea mollissima* Bl., *Cerasus pseudocerasus* (Lindl.) G. Don (chestnut), and *Vaccinium corymbosum* L. (blueberry) etc. Most orchards cultivated one or two fruit trees. There were some weeds (such as *Eupatorium adenophorum* Bidens) living in the understory of orchards.

Wasteland (WL)

Marsh was regarded as the wasteland in this study, which was found near rice fields. Natural marsh vegetation was rarely found in our field work. The main plant species are invasive alien species such as *Alternanthera philoxeroides* (Mart.) Griseb., and *Eupatorium adenophorum* Hort. Berol. ex Kunth, mixed with other typical marsh plants such as *Equisetum ramosissimum* subsp. debile (Roxb. ex Vauch.) Hauke.

Floristic Composition

There was a high vascular plant taxonomic diversity (over 1,000 plant species) found in the investigated fields. A total of 1076 vascular plant species (including subspecies, varieties and form, Supplementary Material B) were identified in the Chaishitan irrigation region, belonging to 165 families and 647 genera (Supplementary Material B). Of these, 23 species (13 families and 16 genera) belong to pteridophytes, accounting for 0.88% of all pteridophyte species in China, whereas 60 species (8 families and 31 genera) are gymnosperms, accounting for 0.8% of gymnosperms species in China. The remaining 993 species (144 families and 600 genera) are angiosperms, accounting for 3.58% of all angiosperms in China. Angiosperm species accounts for 92.29% of all vascular species.

All 1,076 vascular species could be divided into three categories: (1) 295 species (87 families and 226 genera) are wild native species; (2) 748 species (138 families and 462 genera) alien are cultivated species, including vegetables, fruit, aromatic plant, cash crops, and a very large number of garden plant species; (3) 33 species (16 families and 30 genera) are alien invasive species, such as *Eupatorium adenophorum* Hort. Berol. ex Kunth, *Conyza canadensis* L. and *Ageratum conyzoides* Sieber ex Steud.

Poaceae, Fabaceae, and Rosaceae accounted for the most families in Chaishitan irrigation region. Poaceae was represented by the most species (70 species, 48 genera), in which 46 species are wild native species. Fabaceae and Rosaceae were represented by the second (62 species and 36 genera) and the third highest number of species (61 species and 21 genera), respectively. In addition, 49 families were represented by only one species.

Plant Diversity Index

Plant taxonomic diversity indices (i.e., d, He' and Je) differed in different vegetation types. In tree layer, index d, He' and Je are the highest in farmland compared to the other four vegetation types (**Figure 4A**). In shrub layer, d and He' are the highest in Wasteland (WL); however, Je is the highest in Farmland (FL) (**Figure 4B**). In the herb layer, d, He' and Je are the highest in the secondary needle- and broad-leaved mixed forest (SF) (**Figure 4C**).

Rare and Protected Plant Species

Some rare or protected plant species were found in the Greenhouses or Nurseries; i.e., cultivars were mainly for ornamental or medicinal use, and were not wild species, such as *Alsophila spinulosa* (Wall. ex Hook.) R. M. Tryon, *Ginkgo biloba* Linn., *Juglans mandshurica* Maxim., *Pseudolarix amabilis* (Nelson) Rehd., *Glyptostrobus pensilis* (Staunt.) Koch, *Metasequoia glyptostroboides* Hu et Cheng, *Taxus wallichiana* var. *chinensis* (Pilg.) Florin, *Liriodendron chinense* (Hemsl.) Sargent., *Pachylarnax sinica* (Law) N. H Xia et C. Y. Wu, *Phoebe zhennan* S. Lee et F. N. Wei, *Fagopyrum dibotrys* (D. Don) Hara, *Davidia involucrate* Baill., *Sinojackia xylocarpa* Hu, and *Kolkwitzia amabilis* Graebn. were found in our field investigation. These species are listed as national key protected plants species. However, as these were not wild species, their genetic diversity is lower. Furthermore, as there were a large number of individuals of these species, they have a lower conservation value. There were numerous clones of the protected species in the greenhouses and nurseries.

DISCUSSION

Determining a project's evaluation scope is one of the key issues in the EIA procedures (TGEIAEI (Technical Guidelines for Environmental Impact Assessment Ecological Impact), 2011; Liang, 2015; Tan et al., 2015). According to TGEIAEI (Technical Guidelines for Environmental Impact Assessment Ecological Impact) (2011), EIA should fully embody the ecological integrity, covering the directly and indirectly affected areas of all activities of the assessment projects. The scope of evaluation work should be determined by the impact of the evaluation project on

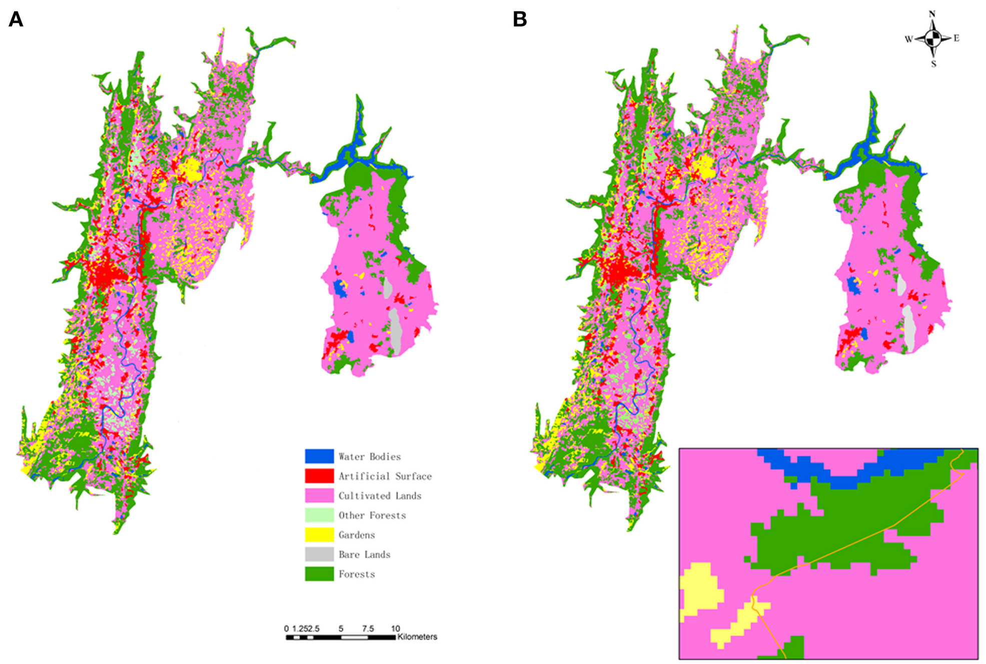

FIGURE 2 | The land-use changes before **(A)** and after **(B)** the Chaishitan water conservancy established.

TABLE 6 | Statistics of pattern metrics in class level.

Land use types / Index (Before / After)	NP	PD	ED	LPI	PLAND	LSI	SHAPE_MN	FRAC_AM
Urban and industrial land	159	0.7358	19.1538	2.4414	9.6234	20.8506	1.5789	1.1245
	187	0.8654	19.5661	2.2053	9.6148	23.994	1.8384	1.1747
Farmland	204	0.9441	74.8151	29.9419	49.704	40.9085	2.0482	1.3375
	311	1.4393	78.4572	20.5175	49.6296	42.8379	1.9444	1.3128
Orchard	1003	4.6417	37.2329	0.6538	10.7541	42.5893	1.5399	1.1328
	1069	4.9472	37.8812	0.6538	10.7404	43.3495	1.5321	1.1312
Other kinds of forest land	220	1.0181	10.8556	0.6994	3.8766	20.8506	1.5789	1.1245
	249	1.1523	11.2246	0.5563	3.8688	21.5579	1.5639	1.1189
Forest land	423	1.9576	36.0051	3.4285	20.0835	30.9984	1.6884	1.1913
	506	2.3417	38.2225	3.082	24.0385	32.6911	1.6657	1.1819
Water	165	0.7636	6.4574	0.2057	1.9585	17.3578	1.5371	1.1096
	179	0.8284	6.5705	0.2057	1.9558	17.6657	1.5211	1.1054
Water conservancy facilities Land	0	0	0	0	0	0	0	0
	16	0.074	7.7765	0.0706	0.1521	73.2723	13.3522	1.6196

Notes: NP, Number of Patches; PD, Patch Density; ED, Edge Density; LPI, Largest Patch Index; PLAND, Percentage of Landscape; LSI, Landscape Shape Index; SHAPE_MN, Shape Index (Mean); FRAC_AM, Fractal Dimension Index (Area-Weighted).

ecological factors, the impact degree and the interaction among ecological factors. We should consider the relationships between the evaluation projects and the climatic processes, hydrological processes, and biological processes. We should take the complete climatic units, hydrological units, eco-units and geographic boundaries as reference boundaries. However, there was no specific evaluation scope regulated in TGEIAEI (Technical Guidelines for Environmental Impact Assessment Ecological Impact) (2011) mainly because of the reasons as follows: First, China has a broad geography with diverse ecosystem types, and

FIGURE 3 | The main land use types in Chaishitan irrigation region.

the projects are complex. Second, different industry guides have clearly defined the scope of the evaluation work; Third, according to the statistics on previous construction projects, most ecological impact assessments have not been carried out in accordance with the evaluation scope recommended by the original guidelines (Liang, 2015; Tan et al., 2015).

In this study, given that the low water temperature and salinity will affect the fish breeding ten kilometers downstream, our evaluation scope included those areas. In the public involvement procedure, we drafted questionnaires and posted them in the places of greatest population concentration to ask local people their opinions and suggestions about biodiversity changes, which helps local biodiversity protection in the future.

"Before-and-after" methods have been applied to previous projects in China. However, some EIA projects did not have systematic (i.e., complete and comprehensive) environment impact assessments for non-natural reserve areas once the project received approval from the government departments, e.g., some assessments only evaluated the status for non-natural reserve areas or neglected plant diversity evaluation in these areas. In this study, we not only evaluated the status before the project was established, but we also systematically evaluated future conditions based on modeling.

The Impact of Chaishitan WCP on Local Landscape

The accuracy of remote sensing depends on the data extraction process (Zhu et al., 2016). In our study, the remote sensing image was from OLI data based on Landsat 8: its resolution is 30 m. Thus, the accuracy defines the meaningfulness of the data. For example, the percentage decline of Farmland and Forestland was 0.079 and 0.066%, respectively. However, if the sensing accuracy is only 70%, these changes are not meaningful at all, because the simple classification error is much greater than the magnitude of changes. Unfortunately, high resolution images are either simply not available or prohibitively expensive, as are images from SPOT (Satellite Pour l'Observation de la Terre) or Quickbird. In this study, based on OLI data from Landsat 8, the CEI before and after Chaishitan WCP was established is 0.92 and 0.89, respectively. Although the CEI decreased by 0.03, both CEI values indicate that

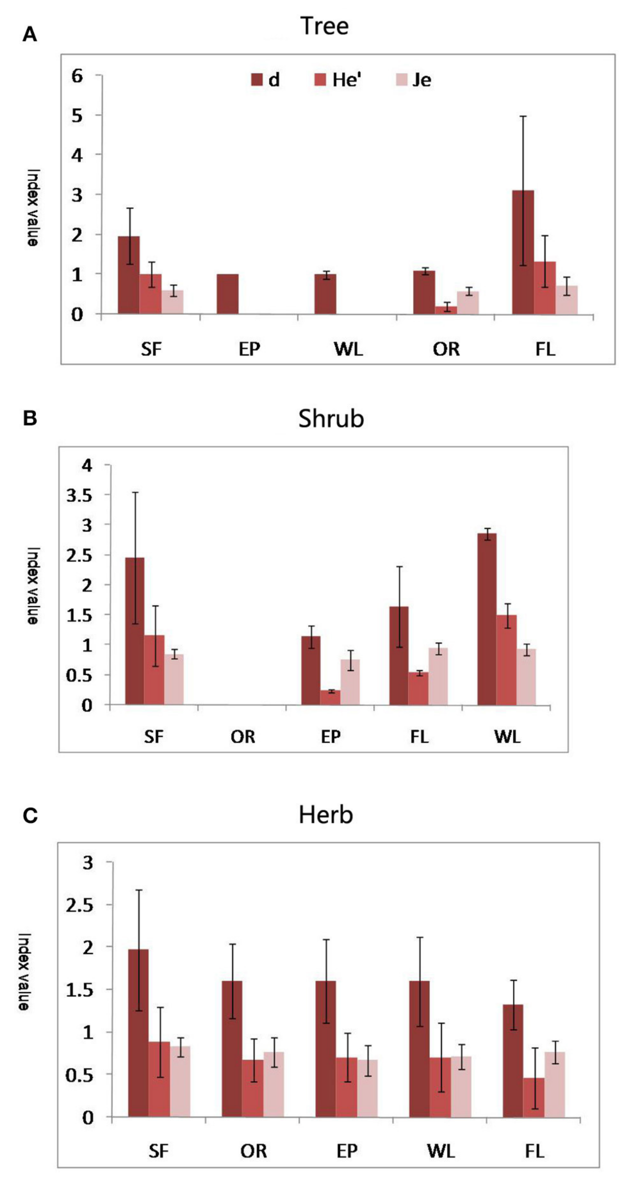

FIGURE 4 | The plant diversity *d, He′*, and *Je* in tree **(A)**, shrub **(B)**, and herb **(C)** layer. SF, Secondary evergreen needle- and broad-leaves mixed forest; FL, Farmland; EP, Eucaluptus plantation; OR, Orchard; WL, Wasteland.

the ecological state is healthy, according to the criteria in Zheng et al. (1994). These values indicate that the Chaishitan WCP will make the CEI decrease slightly, but will not decrease the rank of the overall ecological quality of the Chaishitan region.

Environment Impact Assessments are often conducted before a project is established, can lead to a lack of land use/cover assessments after establishment. In this study, we predicted the changes of land use/cover based on the data from planning diagrams, and found that the structure of landscapes could change after the establishment of the Chaishitan WCP. Specifically, PV, SHDI, PAFRAC, and LDI decreased, while PD, CONTAG, and SPLIT increased, indicating increased landscape fragmentation along with decreases in landscape diversity. The Chaishitan WCP establishment could result in land use change and therefore most landscape indices would change; e.g., PV decreases because the channels or canals would occupy the areas normally containing some natural vegetation, resulting in natural vegetation decreases. On the other hand, the Chaishitan WCP establishment would make the landscape more fragmented, and therefore, the SPLIT will increase due to the generation of more patches.

Shape Feature Analysis

We can see from the column of SHAPE_MN (**Table 5**) that only the land use of urban and industrial land increased, while others decreased, especially for orchards with the least change. This indicates that the shape for urban and industrial land has become more complicated, while other land use types have become more simple or regular after the implementation of the water conservancy facilities. This phenomenon might be caused by the design of this water conservancy facility, which endeavors to have the least disruption to farmland as possible. The situation for SHAPE_MN is almost the same as the index of FRAC_AM, which represents the self-correlation of patches. The value of FRAC_AM is negatively proportional to the impact of human activities. All the FRAC_AM values are very small, which means that all of these land use types are easily affected by human activities.

Landscape Domination Analysis

PLAND and LPI are often used to identify the dominance of the land use type in the whole landscape (O'Neill et al., 1988; Wu, 2000). In this analysis, these two indices indicated that farmland would remain as the dominant land use type after the construction of the water conservancy facilities.

Landscape Fragmentation Analysis

PD and ED are generally combined to analyze the degree of fragmentation for each land use type (O'Neill et al., 1988; Wu, 2000; Wen et al., 2008). By comparing the values of these two indices for all of these land use types, it can be concluded orchard and water bodies have the largest and least degree of fragmentation, respectively. After performing the construction of water conservancy facilities, the degree of fragmentation for all the land used types increased. This means that the water conservation facilities have caused fragmentation of each land use type.

The Impacts of the Chaishitan WCP on Plant Species

In this study, the Chaishitan WCP is predicted to change the area values of different land types (**Table 1**); however, the land use change should not decrease plant diversity because of the three following reasons: first, the change in farmland area (0.161 km^2) and forest land area (0.104 km^2) is limited (**Table 1**). Second, as shown in our field investigation, the Chaishitan project will not occupy natural forest, for all affected forests are secondary forests, plantations or orchards (**Tables 4A,B**). The plant diversity in the farmland and artificial forestland is not high, as most species are cultivated species or alien species, and the species in the forest are widely distributed in that region. Finally, there is no special species sensitive to local habit (Supplementary Material B). On the contrary, Chaishitan WCP might increase the number of local plant species in the long term because once the project is in operation, the human interventions will be reduced, which may create more beneficial habitat or niche for more species due to sufficient water supply.

From a whole ecosystem perspective, the ability of the ecosystem to resist alien species invasion, plant diseases and pest invasion will increase because of sufficient water supply. In the long term, ecosystem stability will depend on multiple factors (e.g., improved soil texture), and the temporary biodiversity decrease should not be reflected in the CEI decrease in the future, because the ecosystem resilience will improve the plant diversity.

An Impact Assessment is an important tool for conservation and sustainable use of biodiversity (IAIA, 2005). There is a growing interest in promoting biodiversity consideration in impact assessments (e.g., IAIA, 2005; CBD (Convention on Biological Diversity), 2006). In order to support this trend, many guidelines and tools have been developed (e.g., World Bank, 2000; OECD (Organisation for Economic Cooperation Development), 2002). Wegner et al. (2005) points out the diversity in definitions and approaches to its assessment among EIA practitioners. Geneletti et al. (2003) further argued that accounting for uncertainty in biodiversity impact assessment—in data, methodologies, and value judgments provided by the experts—is important. Gontier et al. (2006) also address the gap between research in prediction tools and current practice in biodiversity assessment within environmental assessment. Post-project-analysis (PPA) refers to a method and system of tracing, monitoring and confirmatory assessing the environmental impact of constructed projects and the efficiency of preventive measures, as well as proposing remedial plans or measures, aiming to achieve the coordination between project construction and environment (Division of Bill, Resources and Environmental Commission of National People's Congress (DBRECNP), 2003). At present, the PPA in environmental impact in China is basically at the stage of discussing the concept, indicators, methods, content and procedure of the assessment as well as developing case studies (Li et al., 1997; Shen et al., 2005; Cai et al., 2007), while post-project analysis in construction projects is not yet widely conducted. In this study, our assessment was conducted before the project was established, i.e., Before-Project-Analysis (BPA), which could maximally decrease the environmental risk the project brings. In this study, we used modeling predict the land use and plant diversity change immediately after the project established, while as discussed previously, plant could restore to its mature state in a long term (e.g., 5 years, 10 years), therefore, it seems that another comprehensive field investigation is needed to understand what the irrigation system will change. The rare or endangered plant species were found in the greenhouse or nursery, and no wild individuals were found in the investigated field. Furthermore, the irrigation project will provide sufficient water once it is established, which will enrich local plant diversity.

The loss of biodiversity in non-natural reserves is much higher than the loss rate of nature reserves due to over-exploitation, habitat loss, etc. in China (Xia et al., 2005). In this study, we used the Yiliang WCP as an example and we set up hundreds of plant diversity plots to systematically investigate the plant diversity, abundance, and conservation status. Our real intent is to generate more attention the landscape and plant diversity of non-natural reserve areas in China.

CONCLUSION

Systematic environment impact assessment for non-natural reserve areas should be conducted with the same weight as assessments for natural reserve areas, because the baseline for such non-natural areas is needed and too easily neglected. Ignoring these baselines could create data gaps, which in turn could impede future project establishment or environment assessment in a long term. In this study, we proposed a comprehensive evaluation system to assess the potential ecological and environmental consequences of WCP. Our ecological evaluation results showed that the Chaishitan water conservancy project may initially fragment landscape patterns and deteriorate the local ecological conditions. Furthermore, the plant diversity will decrease when the WCP has been constructed. However, the maps of channels indicated that the local diversity will likely rebound and increase in the long term, which will provide beneficial habitat for local species. Therefore, it is appropriate to establish a WCP in Chaishitan irrigation region as long as we model and understand the ecological and environmental consequences of the WCP using well-established socioeconomic evaluation systems.

AUTHOR CONTRIBUTIONS

HW and ZZ conceived this idea, HW, GC, and QL did the field work, remote sensing image interpretation and data analyses, GC and KZ helped creating the figures. HW, CR, and SQ revised the manuscript. All authors contributed to the manuscript.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: http://journal.frontiersin.org/article/10.3389/fevo.2017.00060/full#supplementary-material

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