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Impacts of Pinglu Canal Construction and Its Ecological Route Selection on Landscape Pattern and Suggestions on Environmental Protection

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Abstract. The Pinglu Canal is the first artificial canal since the founding of the People's Republic of China following the Beijing-Hangzhou Grand Canal. It is a major pioneer project for many national strategies, and bears great construction significance. Attractive natural landscape and ecological environment, and abundant tourism and cultural resources along the Pinglu Canal have raised a higher environmental requirement for its construction. In this study, the impact of the planning route of the Pinglu Canal on overall landscape pattern is analyzed from several aspects such as number of patches, mean patch area, largest patch index and fractal dimension. Besides, the impact of multiple routes of some sections on landscape pattern is compared for appropriate route selection. The suggestions for environmental protection strategies of canal construction are proposed from the perspectives of the protection and restoration of ecosystem, as well as the integration of tourism and culture. The results will provide references for landscape pattern impact analysis and ecological protection countermeasures for the constructions of other canals.

Keywords. Environmental protection, landscape pattern, ecological route selection, canal construction

1. Introduction

Traffic corridor, an important part of the landscape ecology, features such fundamental functions as passage, habitat, barrier or transition band, and bears great significance for the energy, materials and biomass in landscape [1]. Human beings have gradually realized series of problems caused by unreasonable project planning and construction to the regional ecological system, while benefiting from the convenient and connected transport empowered by linear transportation infrastructure construction projects. Now, it has been one of key research priorities [2] in the field of environmental evaluation, protection and management to correctly realize and assess the impacts of linear traffic

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corridor construction projects on ecological environment considering such characteristics of linear transportation infrastructure construction projects as long route crossed, wide coverage, as well as the universality and particularity of their impacts on the ecological environment. The ecological system will be sliced as a result of linear transportation infrastructure (roads and railways) construction and operation, which will lead to patch fragmentation of the habitats and partially hinder horizontal ecological flow and species migration, thus resulting in the change in overall landscape pattern over time [3]. The excavation and construction of artificial canals will also impose corridor effects on the regional landscape, and change the landscape pattern. As a result, the continuous overall landscape pattern is transformed into spliced and fragmented landscape mosaics, and the degree of fragmentation is further increased, thus imposing threat on the maintenance of ecological diversity and reducing the stability of ecological environment. While functioning to stabilize soil and beautify the environment, such vegetable restoration countermeasures as construction of bank revetments and greening also change the original ecological landscape features and increase the landscape heterogeneity [4]. Generally, the landscape pattern indexes and spatial correlation analysis methods are applied to analyze the change in landscape pattern caused by construction of linear transportation infrastructure like roads and railways based on the remotely sensed data and site surveys. However, there are currently few studies on artificial canal, although it is within the scope of linear corridor type construction projects.

The evaluation of the impacts of artificial canal construction projects on the ecological environment, especially analysis of the impacts on the landscape pattern, bears great significance for the protection of various complex ecological systems, and is an efficient guarantee for the harmonious coexistence between human beings and the nature. Such evaluations and studies hold a pivotal position in linear transportation corridor and other types of construction projects. In this study, various effects and impacts of excavation and construction of artificial canals are summarized by applying the GIS and Fragstates based on the remotely sensed data, and proper routes are proposed by comparing the landscape pattern impacts of different routes in some river sections. As a result, suggestions for environmental protection are raised from such aspects as ecological landscape protection and restoration, and integration of tourism and culture elements, in a bid to provide reference and basis for the improvement and development of evaluation and studies of ecological environment impacts of linear transportation corridor construction projects, particularly the artificial canals.

2. Methods and Study Area

2.1. Study Area

The Pinglu Canal is the first artificial canal in China after the Beijing-Hangzhou Grand Canal was constructed for more than one thousand years. It will connect the Xijiang River shipping lines and the international seaports in Beibu Gulf, and serve as the shortest access of the Xijiang River to the sea. The construction of the Pinglu Canal has important realistic and profound historical significance for the regional opening up, as well as economic and social development of Guangxi Province or even the vast western region [5]. With the total length of about 140 km, the Pinglu Canal originates from the Pingtang River in Xijin Reservoir Area of Hengzhou city and flows into the Beibu Gulf along the Qinjiang River through the Luwu town in Qinzhou city. Based on investigations in the early stage of the project, the whole route of the canal will be divided into several sections of the Shaping Rivers, the watershed crossing, the main stream in the Qinjiang River and the estuaries. The excavation length of the watershed crossing section will be about 6.5 km, and the other sections will be constructed by utilizing the existed rivers.

2.2. Qualitative Analysis of Landscape Pattern Impact

Based on the current ecological status of the place where the Pinglu Canal construction project is located, the ecological landscape pattern along the canal can be divided into natural banks, semi-natural banks and artificial banks. The original landscape matrix of the natural banks will not be changed by the implementation of the planning, and will consequently have little effect on the landscape ecological pattern of the riparian zone. For semi-natural banks and artificial banks that need to be widened or re-excavated, the construction will seriously affect their landscape ecological pattern, owing to the fact that lots of natural land is occupied whereas the amount of construction land is greatly increased. Therefore, the landscape pattern of these two bank types will be changed from the semi-natural agriculture or natural forest and intertidal zone to the artificial ones. A total of four hub projects will be built during construction. These hubs and reservoirs formed by them will change the original landform, and the natural resource patches will therefore be transformed into artificial disturbance patches. The ecological integrity, connectivity and diversity of the river basin will be affected to some extent, unless the proper measurement is taken [6].

In this study, qualitative impacts of the excavation and construction of artificial canals on the integrity and destruction of regional natural habitat, the succession of plant communities, the destruction of coastal surface vegetation, hindering of wild animals, ecological disturbance, etc. are analyzed from three aspects of regional natural habitats, plant communities, and wild animals.

2.3. Quantitative Analysis on Landscape Pattern

The landscape heterogeneity is a core concept in landscape ecology, which is manifested through the landscape pattern. The changes in landscape pattern, land use, and species and biomass of plants may have strong impact on the regional ecological integrity. The investigation on the impact of the Pinglu Canal on the surrounding landscape pattern equals to the evaluation on the effect of the landscape pattern formation by construction of canal, which is regarded as an important element in landscape structure [7]. In addition, the corridor density, landscape fragmentation and landscape connectivity are closely correlated with the landscape pattern [8]. Therefore, the contributions of the canal construction planning to both fragmentation and connectivity degree of regional landscape pattern are evaluated, and the quantitative analysis for regional ecological integrity is conducted considering the vision to minimize the impact on the main regional natural ecological function, with a bid to estimate the possible impact of the planning and construction of the Pinglu Canal on its riverine landscape pattern.

In the present study, the patch-level, class-level and landscape-level landscape indexes are adopted to characterize the spatial distribution of the overall landscape. The patch-level index is not of great significance for the understanding of the entire landscape structure, thus it is only used for calculating other indexes. Besides, the class-level index has little significance for the evaluation in this study, since the patch types along the Pinglu Canal are not obviously changed by its construction. Accordingly, based on the use of the landscape type map and consideration of the ecological significance for landscape indexes and their correlation, the number of patches, mean patch area, largest patch area index and fractal dimension after the construction of the Pinglu Canal are calculated and compared with their original level. The detailed calculation method and ecological significance of the relevant indexes are derived from Landscape Ecology and Fragstats Technical Manual Package. These indexes have been widely used in ecological landscape pattern analysis, with proved feasibility. In order to accurately analyze the impact of the Pinglu Canal on ecological landscape pattern, the situation before and after the canal construction, which is respectively called current scenario and target scenario, are analyzed.

Number of patches (NP; pcs, NP ≥ 1). NP is the total number of a certain type of landscape patch at the type level, and equals to the total number of all landscape patches at the landscape level. NP is usually used to describe the heterogeneity of the entire landscape, and it is often positively correlated with the degree of landscape fragmentation. Generally, the greater NP value indicates the higher fragmentation degree.

Largest patch index (LPI; %, 0 < LPI ≤ 100). LPI represents the proportion of the largest patch in the total area of a certain landscape type, reflecting the dominant type of landscape in addition to the strength and direction of human activities. The value of LPI determines the ecological characteristics, such as the dominant species and the abundance of internal species in landscape.

Mean patch area (AREA_MN; ha). The mean patch area of a certain region is always related to the fragmentation of this region. The larger mean patch area reflects lower fragmentation degree. AREA_MN is the mean area of different patch types in a certain landscape, and is used as another indicator for the fragmentation degree of regional landscape.

Fractional Dimension (dimensionless, 1-2). The fractional dimension is the non-integer dimension of irregular geometries, reflecting the impact of human activities on landscape pattern. The natural geographical boundaries are always more complex than artificial ones, for example, the boundary between river and mountain is much more complex than that between city and farmland. Therefore, the complexity of patch boundary can be used as an important tool for the intensity evaluation of land use. This index can be regarded as a negative effect indicator. Typically, the higher fractional dimension suggests the lower development intensity, whereas the lower fractional dimension indicates the greater development intensity. In the present study, the area-weighted mean fractional dimension (FRACC-AM) is used for analysis.

2.4. Ecological Route Selection Optimization

The impact of the route on ecological environment is the most important factor to be considered in route selection for linear transportation infrastructure in addition to topography, social, economic and other factors. In ecological route selection, what's more important is to consider the impacts of route on ecological landscape pattern in addition to the necessity to pass round various ecological environmental protection objectives. In this study, the impacts of four sections of the Pinglu Canal on the regional landscape pattern along the route before and after the construction are analyzed and used as the reference, and focus is placed on the comparison of the impacts of two different route schemes of watershed section and estuary section on the landscape pattern before and after the construction. As a result, the route with smaller impact on the regional landscape pattern is recommended as an optimized scheme. Four indexes of the number of patches (NP), proportion of the largest patch index (LPI), mean patch area (AREA_MN) and area-weighted mean patch fractal dimension (FRAC-AM) are used in landscape pattern analysis. Generally speaking, if NP increases obviously and AREA MN decreases more after the canal is constructed based on a certain route scheme, it means that the degree of landscape fragmentation in the region will increase if the canal is constructed based on this route scheme, indicating that such route has great impact on the regional landscape pattern.

3. Results

3.1. Qualitative Analysis of Landscape Pattern Impact of Pinglu Canal

(1) Impact on the regional natural habitats

Impact on the integrity of natural habitats. The newly excavated and cut-off banks will divide the surrounding complete natural habitat into fragments and will result in the insularization of natural habitats, which is adverse to the preservation of originality of the regional natural habitats. These may induce changes in the adaptability of natural habitats and affect their integrity.

Destruction of natural habitats. Some of the paddy fields, dry lands, forests and grasslands will be permanently occupied due to construction of the canal, which will result in the loss of their original production capacity and consequently destroy the habitats of animals and plants. Overall, the construction and operation of the canal may directly lead to decreased number of animals and plants, and loss of biomass, biodiversity and ecosystem function in the construction area [9].

Ecological disturbance. The engineering activities during construction like clearing, filling and excavation may change the soil density, landscape characteristics, subsurface and surface runoff, microclimate characteristics, land use, as well as the composition of vegetation and habitats along the banks of the river, thus causing the ecological disturbance to some extent. In particular, the wetlands and other aquatic environments on both sides of the river are the most sensitive parts to the canal construction; some of water in their aquifers may be deplete by the embankment and excavation, which will increase the possibility of soil erosion and landslides, and eventually cause the sediment-induced contamination in waterways.

(2) Impact on the plant communities

Impact on the vegetation along the canal. The temporary lands and dredged material stacking areas during construction can cause the reduction or destruction of vegetation along the river banks. In the meantime, the rolling of construction machines and the trampling by construction personnel can also partly affect the vegetation surrounding the construction sites [10].

Impact on the succession of plant communities. During construction of the forest-crossing routes in watershed section, some of the forests will be felled. With the flows of people and vehicles, vegetation layers of shrubs, herbs and trees are all obviously destroyed, which will lead to the biodiversity reduction, the hierarchy loss and the vertical structure change of local communities [11]. Due to the lack of the protection and promotion from underwood and shrubs, the arbor layer will gradually be less resistant to the environment and more vulnerable to diseases and wind breakages. This may lead to the reduction of system's adaptability, adjustment and stability, further ceasing their succession or even causing the retrogressive succession.

Ecological disturbance. Air pollutants and dust can be produced by shipping vessels after the canal is built, and these pollutants may be carried and deposited on plants along the canal. The epiphytic lichens in wetland are especially more sensitive to such pollutants [12]. Some heavy metals and trace elements, such as Pb, Zn, Cu, Cr, Cd and Al, can be accumulated in plant and animal tissues and affect their reproduction and survival. Some toxic pollutants, for example, polycyclic aromatic hydrocarbons, ozone, nitrogen oxides and chemical fertilizers, may affect the survival of vegetation on both sides of the canal to different extents.

(3) Impact on the wild animals

Hindering effect. The inhibition of the newly-built canal on wild animals is resulted from the combined effect of the physical barrier and habitat avoidance for vessel noise, pollution and human activities. The shipping vessels will also reduce the biomass of animals in the riverway.

Ecological disturbance. With the increase of vessel traffic, the ecological disturbance for wild animals can be induced by noise and visual disturbance including artificial lighting and/or shipping vessels. The species with larger size, longer longevity, lower reproductive rate and more rarities, as well as those living in occluded habitat and/or depending on native habitat, are more easily to be affected by the noise disturbance from shipping vessels.

3.2. Quantitative Analysis of Landscape Pattern Impact of Pinglu Canal

Classification of land use data. In this study, the data of land use types in Guangxi Province in 2018 is used and classified by Arcgis 10.1. The land types closely correlated with the evaluation for the impact of the canal on regional landscape pattern, i.e., forests, grasslands, paddy fields, reservoirs, ponds, intertidal zones and beaches, are classified as ecological space; rivers and lakes are classified as water system; other land use types are not considered. In the meantime, the 10 km within both banks of the recommended route for the Pinglu Canal is included for the pattern analysis in this study (Figure 1).

Buffer analysis. The 100 m of buffer boundary is set for all water systems by Arcgis 10.1. The canal route is also imported into Arcgis 10.1 to generate the buffer boundary within 100 m from the center line of the canal (Figure 2).

Calculation of landscape index. The data of land use before and after the canal construction is obtained by the above steps for evaluation. They are transformed into the raster form and then imported into Fragstats 4.2. The landscape indexes of landscape scale and patch type scale are selected according to the needs of investigation, and the corresponding calculation results are obtained using the standard analysis in software.

The data analysis for the overall landscape pattern index of the recommended route is conducted, and the results are listed in Table 1. The number of regional patches obviously increases after the canal construction along the recommended route. Although the largest patch is rarely affected, the mean patch area decreases, whereas the regional landscape fragmentation degree significantly increases. Besides, the fractional dimension increases slightly. This may attribute to the increase in the number of patches. Moreover, a lot of cut parts of the cut-off banks during construction are not considered as being filled, which may also cause the increase of the fractional dimension.

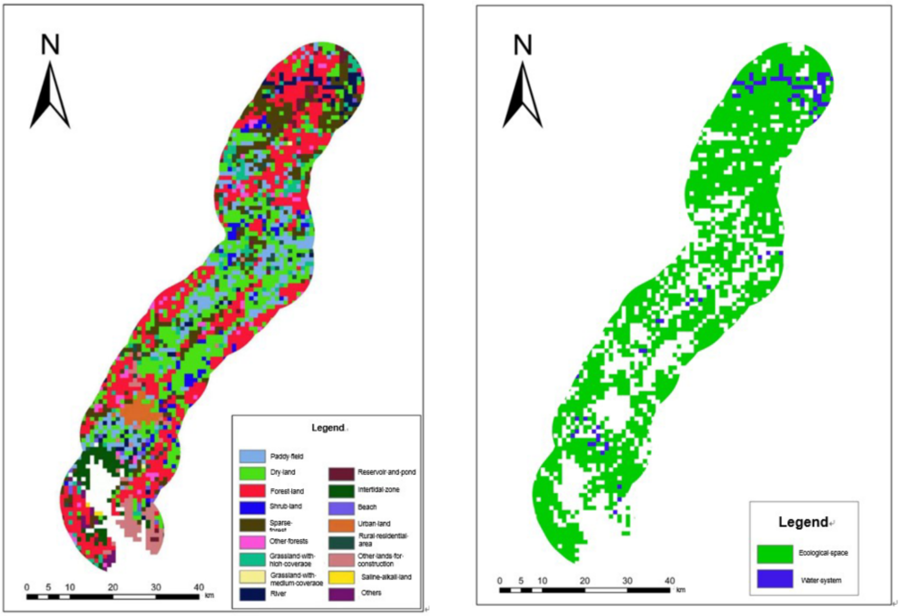

Figure 1. Land use types before and after classification.

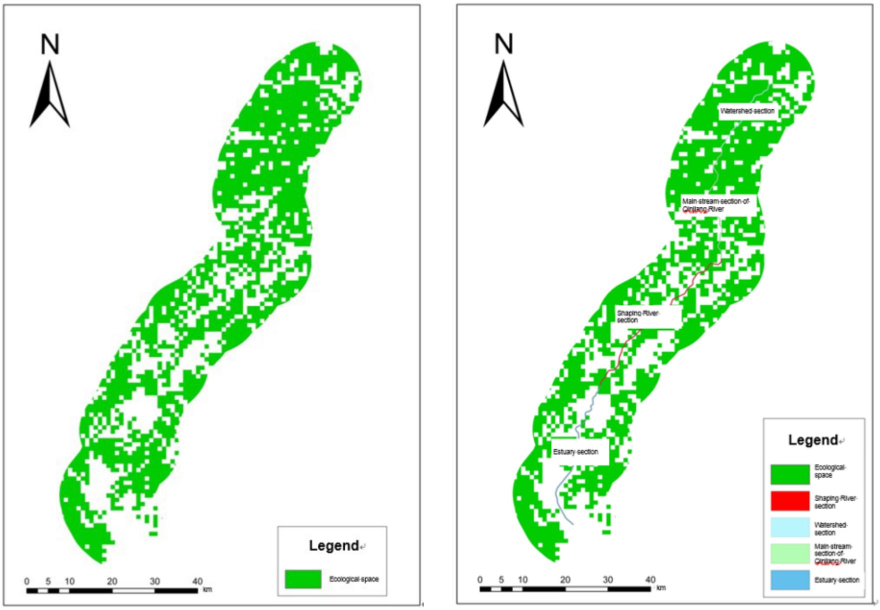

Figure 2. Base maps before and after the superposition of the canal.

Table 1. Data analysis for the overall landscape pattern index of the recommended route.

Scenario type	NP	LPI	AREA_MN	FRAC_AM
Current scenario	14	99.2355	12772.16	1.2356
Target scenario	25	98.9492	7106.573	1.2398

3.3. Ecological Route Selection Optimization of Pinglu Canal

In this study, the landscape pattern analysis along the four sections of the canal is conducted, and the comparison analysis of different schemes for the watershed and the estuary sections is also performed. The specific results are shown in Tables 2-7.

Table 2. Analysis on landscape pattern indexes of the Shaping River section.

Scenario type	NP	LPI	AREA_MN	FRAC_AM
Current scenario	2	99.9807	27474.30	1.1640
Target scenario	2	99.9806	27307.94	1.1725

The construction of the canal in the Shaping River section has less impact on the regional landscape pattern, demonstrated by the unchanged number of patches, and the stable status for area of the core patch, mean patch area, fractional dimension and landscape fragmentation degree (Table 2).

Table 3. Analysis on landscape pattern indexes of the top route scheme for the watershed section.

Scenario type	NP	LPI	AREA_MN	FRAC_AM
Current scenario	4	99.6646	15222.22	1.1889
Target scenario	5	99.6143	12120.59	1.1931

Table 4. Analysis on landscape pattern indexes of the outfall route scheme for the watershed crossing section.

Scenario type	NP	LPI	AREA_MN	FRAC_AM
Current scenario	1	100	83642.13	1.0814
Target scenario	2	99.9981	41555.16	1.1022

There are two route schemes for the watershed section, i.e., the top route and the outfall route (Tables 3 and 4). Obviously, the outfall route for the watershed section poses great impact on the regional landscape pattern, with higher values of most indexes and higher landscape fragmentation degree compared with the top route scheme. This may be caused by the fact that the watershed section belongs to the banks need to be newly excavated, and the type of landscape patches in areas those the outfall route passes through is relatively abundant. However, the impact of these two schemes on the regional landscape pattern is limited and they impose low risk on ecological environment.

Table 5. Analysis on landscape pattern indexes of the main stream in the Qinjiang River.

Scenario type	NP	LPI	AREA_MN	FRAC_AM
Current scenario	6	99.1377	11254.67	1.2238
Target scenario	11	98.6683	6110.804	1.2249

The number of patches in the mainstream of the Qinjiang River increases significantly after the canal construction, whereas both the mean patch area and the area of core patch decrease (Table 5). However, the impact is also limited. In general, there are many cut-off banks in this section, leading to the obvious cutting of patches, the increased number of patches and higher landscape fragmentation degree. These probably contribute to the results in this study.

Table 6. Analysis on landscape pattern indexes of the Jingu River waterway route scheme for the estuary section.

Scenario type	NP	LPI	AREA_MN	FRAC_AM
Current scenario	5	97.3387	13784.04	1.1506
Target scenario	10	92.9943	6855.606	1.1465

Two route schemes including the Jingu River waterway and the Shajing River waterway are proposed for the estuary section. As shown in Tables 6 and 7, the former route scheme can pose greater impact on the core patch in the regional landscape pattern, illustrated by greater decrease in the mean patch area and higher degree of landscape fragmentation.

Table 7. Analysis on landscape pattern indexes of the Shajing River waterway route scheme for the estuary section.

Scenario type	NP	LPI	AREA_MN	FRAC_AM
Current scenario	4	98.3318	18120.47	1.1514
Target scenario	8	98.1869	9033.806	1.1539

Based on the overall landscape pattern analysis of the recommended route, the results indicate that the existence of multiple cut-off banks in the Pinglu Canal planning may induce the decrease in regional mean patch area and the increase in patch number and landscape fragmentation degree. However, they impose low impact on the area of the largest patch, and the core patch is consequently protected. Therefore, the risk posed by the canal construction is low and generally controllable. Besides, the cut parts of the cut-off banks can be used for creating abundant wetland environments to mitigate the impact on regional ecology. From the perspective of the segmented landscape pattern analysis, the impact of the top route scheme for the watershed section on regional landscape pattern is lower than that of the outfall route scheme, and the impact of the Jingu River waterway route scheme for the estuary section is lower than that of the Shajing River waterway route scheme. Accordingly, the two former schemes are recommended for maintain landscape pattern and controlling ecological risk.

4. Suggestions for Ecological Landscape Protection along the Pinglu Canal

4.1. Protection and Restoration of Ecological Landscape

The original natural river will be artificially divided into several sections to form multiple channel reservoirs during construction of the Pinglu Canal. This may not only change the overall natural landscape along the river basin, but also pose some impacts on the regional landscape pattern. Although there are not serious impacts on ornamental value and ecological risks, the continuity and integrity of the natural landscape along the river basin are damaged to some extent [13].

On the whole, the original natural curves of rivers in the cut-off banks are suggested to be preserved and restored during construction, and to be utilized to create various types of wetland landscape with the planting of aquatic vegetation. Moreover, the isolated wetlands can be connected by constructing culverts and pipelines. In the meantime, the natural planting of the local tree species should be added considering the original landscape styles along the canal to largely maintain the original status of corresponding landscape, whereas the tall trees that may obscure visions are not recommended. The regular planting can be appropriately used along the banks of some ship locks and docks, in order to build the cultural landscape. For the construction of canal revetments, the bionic slope protection with vegetation can be adopted as far as possible. The large artificial structures can be softened by plants to promote the coordination and integration of the canal and its surrounding natural environment.

4.2. Integration with Tourism and Culture

The Pinglu Canal will be another milestone after the construction of typical ancient canals like the Beijing-Hangzhou Grand Canal and the Ling Canal. The Pinglu Canal not only bears important functions in shipping and water conservancy, but also plays a significant role in history, culture, education and tourism.

Therefore, it is suggested to focus on the integration of tourism and culture during construction. The rich tourism resources in Nanning and Qinzhou along the Pinglu Canal can be blended to build a water tourism route characterized by the main line of the canal and the branch line of riparian scenic spots. In the meantime, the wetlands in the cut-off banks can be fully combined with the functions of bird watching, education and scientific research, to enrich the products of water tourism. Some artificial facilities such as docks and slope protections of the canal can be utilized to create the special cultural ties and landscape in combination with the regional culture along the route, further enhancing the humanistic landscape of the canal.

5. Conclusion

The construction of artificial canal imposes great impact on the regional landscape pattern and this study bears great significance for the environmental impact assessment of the canal construction project. In this study, the methods for analysis of impacts of artificial canal construction on regional landscape pattern and ways to optimize the local ecological route selection are analyzed. The results show that different route schemes will impose different impacts on the landscape pattern. New routes and bank sections with more cut-offs impose greater impacts on the regional landscape pattern. In addition, some suggestions are also proposed to reduce the impacts of canal construction on ecological environment by protecting and restoring ecological landscape from the construction period to the operation period. Currently, the study is only limited to the analysis on the impacts of artificial canal, a single linear transportation infrastructure, on the landscape pattern. In the next step, more studies are needed to assess the impacts of artificial canal excavation on regional ecological system in combination with the evaluation of impacts of the traffic corridor network formed by the road network, railway network and canal projects on large-scale ecological environment or landscape pattern at the regional scale.

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