



Ecological Environment Evaluation of Liuxi River Basin During Rapid Urbanization

Yunwen Xie^{1,2}, Xulong Liu^{1,3(✉)}, Zhifeng Wu², Ji Yang^{1,3},
and Jingjun Zhang⁴

¹ Key Laboratory of Guangdong for Utilization of Remote Sensing and Geographical Information System, Guangdong Open Laboratory of Geospatial Information Technology and Application, Guangzhou Institute of Geography, Guangzhou 510070, China

lxlong020@126.com

² School of Geographical Sciences, Guangzhou University, Guangzhou 510006, China

³ Southern Marine Science and Engineering Guangdong Laboratory (Guangzhou), Guangzhou 511458, China

⁴ Xinhua College of Sun Yat-Sen University, Guangzhou 510520, China

Abstract. This article takes Liuxi River Basin in Guangzhou as the research object, selects Landsat remote sensing data of 1993, 2000, 2011 and 2018 as data source, to access the five indices, including vegetation coverage, DEM, land use, soil index and slope. The comprehensive index method is used to obtain the ecological environment comprehensive index of this study area. The environmental quality is divided into 4 grades. The ecological environment of the basin and its dynamic changes have been comprehensively evaluated in the past 25 years. The results show that: In the Liuxi River Basin in 2018, the percentage of excellent natural ecological environment quality was 4.80%, the percentage of the areas with good quality was 44.53%; the percentage of the areas with general quality was 45.97% and the percentage of the areas with poor quality was 4.68%. Overall, the good and the general ecological environment quality is the majority. From the perspective of time from 1993 to 2018, the percentage of the area with excellent environmental quality increased by 1.69%; the percentage of the area with good environmental quality gradually decreased, with a total of 32.88%, but still occupied the largest proportion; The percentage of area with general environmental quality went up and down, with a total of 29.64%; the percentage of the area with poor environmental quality rose by 1.54%, the overall change was not big. The downstream ecological environment is showing a trend of deterioration. In upstream, the excellent ecological environment is the majority. The overall ecological environment of the river basin is developing for the better.

Keywords: Natural ecological environment · Remote sensing · Evaluation · Liuxi River

1 Introduction

Ecological environment evaluation is a qualitative or quantitative analysis of the quality level of the ecological environment in the study area from a specific perspective [1]. Scientific understanding, reasonable evaluation and optimized regulation of the regional ecological environment are not only the basic work of regional development planning and ecological environmental protection, but also an important criterion for objectively measuring the healthy and sustainable development of the region [2]. Applying remote sensing technology to ecological environment evaluation can save the manpower and material resources required by the field monitoring and investigation, and achieve rapid monitoring of the ecological environment [3]. The watershed is a comprehensive ecological system including nature, society, and economy, and is an independent and complete ecological landform unit, which has the characteristics of its own environment within the region. Almost all ecological and environmental problems and the irrational use of resources can fall into the scope of a specific river basin. Therefore, solving the environmental problems from the perspective of the river basin is a way that can achieve sustainable development more effectively in a comprehensive and systematic manner [4].

Liuxi River is the main source of water supply for Huadu District and Baiyun District and the main drinking reserve water for downtown Guangzhou as well. It's a part and parcel of Guangzhou city water supply security system. In the situation of rapid urbanization, the impact of human activities on drinking water sources is becoming more serious. Watershed ecological environment quality evaluation is an important method to judge the safety of drinking water sources. Environment protection administration monitoring data indicates that the overall index of the main downstream water quality is at the level of category 5, far from meeting the requirements for water environment function zones. In early 2013, the operation based on Guangdong's water clearing plan of the Guangdong environment protection bureau focused on improvement and protection of the water quality of the Liuxi River; the regulations on the protection of Liuxi River Basin in Guangzhou have been implemented since June 1, 2014. The comprehensive plan for Liuxi River Basin in Guangzhou (2015–2030) proposes to slow down the hydrological effects of urbanization, reduce the interference of human activities, and establish an ecological environment system with rich cultural deposits, harmonious landscapes, and a harmonious relationship between people and water. A lot of attention is paid to the water quality of the Liuxi River by the public. Therefore, in order to strengthen the water environmental protection and management of Liuxi River Basin, enhance the ability to prevent floods and droughts, and systematically and comprehensively protect the drinking water sources in Guangzhou, it is of strategic significance for study personnel to understand the ecological environment and changes in the region in a timely manner.

Most of the existing studies on ecological environment assessment take administrative units as the evaluation units, and there are few studies on river basins. The advantages of remote sensing technology have not been fully reflected. The study of Liuxi River Basin mostly focuses on water quality, water environment, flood forecasting, etc., and its overall ecological environment assessment is relatively insufficient. Based on this, this article takes the Liuxi River Basin in Guangzhou as the research

object, and uses Landsat remote sensing data from 1993, 2000, 2011, and 2018 as the data sources to assess vegetation coverage, DEM, land use, soil index, and slope. The comprehensive index method is used to obtain the comprehensive index of the ecological environment in the study area. According to its quality status, it is divided into 4 grades of excellent, good, average, and poor. The ecological environment status of the river basin and the ecological environment changes in the past 25 years are comprehensively evaluated. This study provides technical support for timely understanding of the ecological environment in the region and formulating scientific ecological environment protection measures.

2 Data and Methods

2.1 Study Area

The Liuxi River originated in the northeast of Conghua District, Guangzhou, the area between Dalingtou and Guifeng Mountain which is at the junction of Lutian County and Longmen County (Fig. 1). Flow through Huadu District, Luogang District, Baiyun District. After passing through the river network of the Pearl River Delta, and finally injected into the South China Sea, 157 km in total. Located between $113^{\circ}10'12'' \sim 114^{\circ}2'00''\text{E}$ and $23^{\circ}12'30'' \sim 23^{\circ}57'36''\text{N}$, Watershed area of 2290 km^2 , 2225.72 km^2 is in Guangzhou and 33.28 km^2 is outside Guangzhou, is an important ecological barrier in the north of Guangzhou, There are Liuxihe Forest Park, one of the top ten forest parks in the country, and Liuxihe Reservoir, the only large reservoir in the city. The average rainfall for many years is 1823.6 mm, which belongs to the subtropical monsoon climate zone with mild climate and abundant rainfall. The upstream channel of Liuxi River, which is about 10 km above Liangkou Town, passes through the deep mountain canyon. The average slope of the river bed is 1/1250, and the water flow is turbulent. In the middle and lower reaches of Wenquan Town and below, the average slope of the river bed is reduced to 1/2500, the water flow is relatively gentle. The population of the basin is about 300,000. Since 1995, the urbanization of the Liuxi River Basin has entered a stage of rapid development, and the area of cultivated land has decreased sharply. The ecological environment of the Liuxi River Basin has suffered to varying degrees under the background of urbanization.

The Liuxi River originates in the northeast of Conghua District, Guangzhou and flows through Huadu District, Luogang District, Baiyun District. After passing through the river network of the Pearl River Delta, it finally empties into the South China Sea, with a length of 157 km in total. Located between $113^{\circ}10'12''$ and $114^{\circ}2'00''\text{E}$ and $23^{\circ}12'30''$ and $23^{\circ}57'36''\text{N}$, it has a watershed area of 2290 km^2 , with 2225.72 km^2 in Guangzhou and 33.28 km^2 outside Guangzhou. It is an important ecological barrier in the north of Guangzhou. There are Liuxi River Forest Park, one of the top ten forest parks in China, and Liuxi River Reservoir, the only large reservoir in the city. The average rainfall for many years is 1823.6 mm, which means it belongs to the subtropical monsoon climate zone with a mild climate and abundant rainfall. The upstream channel of the Liuxi River, which is about 10 km away from Liangkou Town, passes through the deep mountain canyon. The average slope of the river bed is 1/1250, and

the water flow is turbulent. The average slope of the riverbed was reduced to 1/2500, the water flow is relatively gentle. The population of the basin area is about 300,000. Since 1995, the urbanization of Liuxi River Basin has entered a stage of rapid development, and the area of cultivated land has decreased sharply. The ecological environment of Liuxi River Basin has suffered to varying degrees under the background of urbanization.

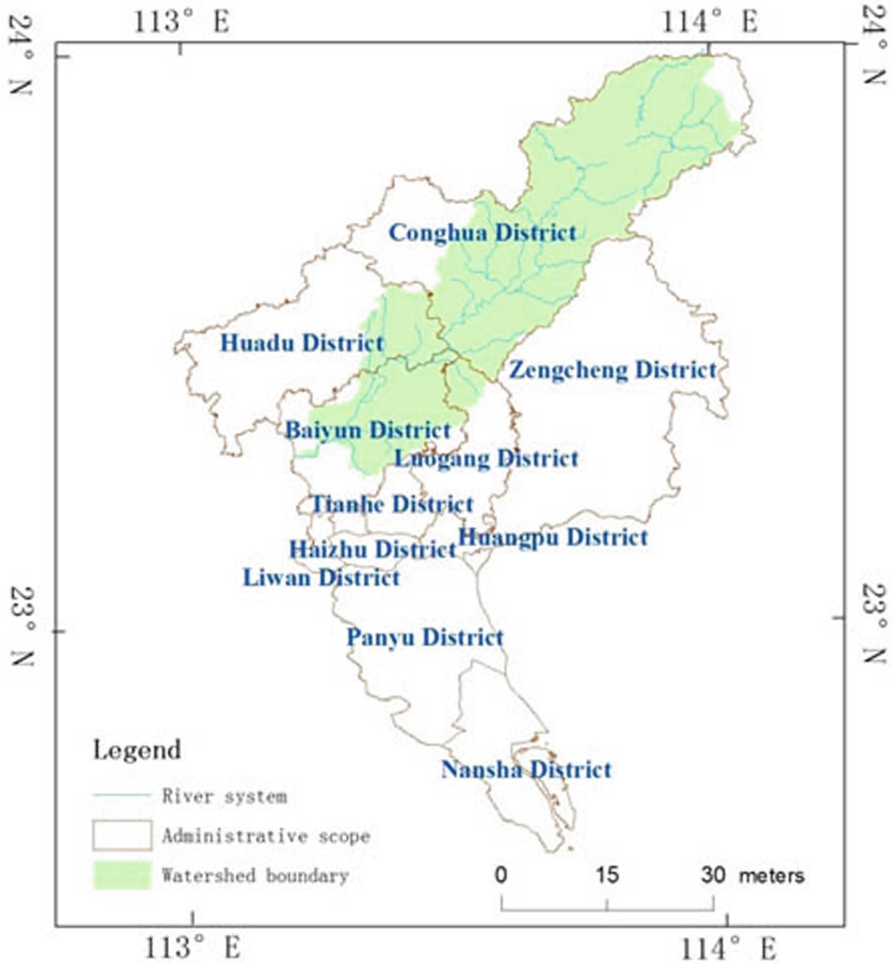


Fig. 1. Geographical location of the study area

2.2 Data Pre-processing

The main data used in this research comes from the geospatial data cloud (<http://www.gscloud.cn/>), including Landsat images and DEM data covering Liuxi River Basin. In order to form a uniform data format, preprocessing was performed under the support of

ENVI5.3: the Landsat image obtained was subjected to projection conversion, radiation calibration, and atmospheric correction processing. The purpose of image atmospheric correction is to eliminate the effects of atmospheric conditions and lighting conditions on surface reflectivity. The corrected image basically removes the influence of water vapor particles and other factors in the air, the spatial difference of the types of ground features has been improved [5], and the reflection spectrum curve has become normal. Then the Liuxi River boundary is used as the ROI for stitching and cropping, and finally the processed remote sensing image map is obtained.

2.3 Research Methods

This article is based on the standards of Technical Specification for Eco-Environmental Status Evaluation (HJ192-2017), combining the actual situation of rapid development of Liuxi River urbanization and the principles of easy availability of ecological factors, scientificity and independence, Selecting the five basic factors of vegetation coverage, DEM, land use, soil index, and slope as the ecological factors for evaluating the ecological environment of Liuxi River Basin, and normalizing the above-mentioned five ecological factor indicators, the comprehensive index method was used to evaluate the ecological environment of the study area, and finally the ArcGIS software was used to generate the hierarchical map of ecological environment assessment. Technology roadmap is shown in Fig. 2.

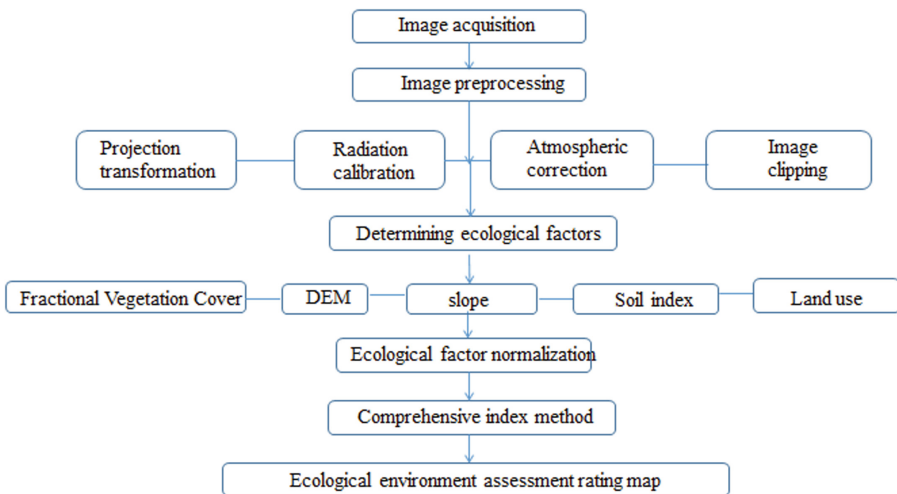


Fig. 2. Technology roadmap

2.4 Remote Sensing Ecological Index

In this paper, vegetation coverage, DEM, land use, soil index, and slope are selected as ecological factors to evaluate the ecological environment of Liuxi River Basin. Fractional Vegetation Coverage (FVC) is often used to study vegetation changes, ecological environment research, soil and water conservation, and climate. This study uses remote

sensing estimation method [6], the sensor can detect vegetation information mainly because the green plant canopy has spectral characteristics with high reflectivity in the red and near-infrared bands. Based on this, the ecological status of green vegetation on the regional scale is evaluated [7]. The calculation formula of vegetation coverage is as follows:

$$FVC = (NDVI - NDVI_{min}) / (NDVI_{max} - NDVI_{min}) \quad (1)$$

NDVI is a normalized index, and $NDVI_{max}$ and $NDVI_{min}$ are the maximum and minimum values in the region, respectively. Due to the inevitable noise in the image, $NDVI_{max}$ and $NDVI_{min}$ are not necessarily the maximum NDVI value and the minimum NDVI value. You need to set the confidence value (empirical value) to select. The NDVI calculation formula is as follows:

$$NDVI = (TM4 - TM3) / (TM4 + TM3) \quad (2)$$

Among them: TM4 and TM3 are the reflectance of Landsat ETM near infrared and red band, respectively.

The soil index adopts the widely used bare soil vegetation index model (GRABS) [8]. The specific algorithm is as follows:

$$GRABS = VI - 0.09178BI + 5.58959 \quad (3)$$

BI is the soil brightness index (the first component), and VI is the greenness index (the second component); BI has a considerable impact on the vegetation index, because the main part of the information change of the bare soil is caused by their brightness; There is great correlation between VI and different vegetation cover. Since the first and second components are concentrated >95% of the information, they can well reflect the differences in spectral characteristics such as vegetation conditions and soil moisture content, organic matter content, particle size, mineral composition and surface roughness, therefore, the bare soil vegetation index formed by the linear combination of BI and VI can well reflect the bare condition of the soil.

The change of the terrain gradient has a significant impact on the growth and distribution of surface vegetation and the soil anti-erosion ability. For soil erosion, under the same vegetation coverage, the area with greater terrain slope has a worse surface soil anti-erosion ability and the smaller the terrain slope, the stronger the resistance to erosion, and the larger the index value [9]. The slope index is obtained on the basis of the DEM image. The obtained two-scene DEM images are stitched, the boundary vector data of the Liuxi River administrative region is projected and transformed, and the Liuxi River Basin boundary is used as the ROI for cropping to obtain the Liuxi River Basin DEM data. The slope index can be directly generated through the Topographic Modeling module using ENVI.

Land use is classified using unsupervised classification. First, by setting reasonable parameters, a training template file (SIG) and a spectral clustering image are obtained, and then the training template file is edited, evaluated, and adjusted to form a classification template that finally meets the requirements. Using this classification template as a training sample for supervised classification and supervised classification using the

minimum distance method, the land use map of the study area can be obtained. Formed six first-class categories including cultivated land, forest land, grassland, waters, urban and rural industrial and mining residents' land, and unused land. Finally, 120 points were randomly selected for verification, and the overall accuracy reached 92%, and the classification accuracy reached practical requirements.

2.5 Normalization of Ecological Factors

In the study, the indicators are standardized. The data of each participating factor after normalization is a set of values that reflect its attribute characteristics. The values of all indicators are within the range of [0, 10]. According to the scores of each indicator and its contribution to the quality of the ecological environment, the principle of uniform order is adopted. That is, according to the magnitude of their positive impact on the ecological environment, they are divided into several levels from high to low, and the greater their contribution to environmental quality, the smaller the code value. The vegetation coverage, DEM, soil index, slope, and land use are divided into 10 levels according to Table 1 and re-assigned. The larger the code, the better the ecological environment. The land use treatment method is used to understand the use of each land type and its impact on the ecological environment, and then the analytic hierarchy process is used to determine the weight of each land use type, and then they are re-encoded.

Table 1. Comparison of ecological factor normalization code values

Coded value	Fractional vegetation coverage	Soil index	Slope	DEM
1	0–10	–439.04 to –394.58	78.3–87.0	929.12–1039.91
2	10–20	–394.58 to –350.12	69.6–78.3	818.33–929.12
3	20–30	–350.12 to –305.65	60.9–69.6	707.54–818.33
4	30–40	–305.65 to –261.19	52.2–60.9	596.75–707.54
5	40–50	–261.19 to –216.73	43.5–52.2	485.96–596.75
6	50–60	–216.73 to –172.26	34.8–43.5	375.18–485.96
7	60–70	–172.26 to –127.80	26.1–34.8	264.39–375.18
8	70–80	–127.80 to –83.34	17.4–26.1	153.60–264.39
9	80–90	–83.34 to –38.87	8.7–17.4	42.81–153.60
10	90–100	–38.87 to 5.58	0.0–8.7	–67.97 to 42.81

The assessment method used in this study is the comprehensive index method, and the calculation formula is as follows:

$$E = W_1 * S_1 + W_2 * S_2 + W_3 * S_3 + W_4 * S_4 + W_5 * S_5 \quad (4)$$

Among them, E is the result of ecological environment assessment, S1 is vegetation coverage, S2 is DEM, S3 is slope, S4 is land use, and S5 is soil index. W_i ($i = 1,2,3,4,5$) is the weight of each coefficient, which is determined by the analytic

hierarchy process. The analytic hierarchy process is that several factors that affect the target are divided into several criterion layers. Comparison between each other, the qualitative indicators are blurred to get the weight of each factor. W_1 , W_2 , W_3 , W_4 , and W_5 take 0.4534, 0.2473, 0.1442, 0.1009, and 0.0542, respectively. Because the threshold of the ecological environment assessment results is not uniformly and clearly defined [10]. Referencing to the ecological environment assessment in the “Technical Specifications for the Evaluation of Ecological Environment Conditions (HJ192-2017)”, and combines the relevant literature and the specific conditions of the Liuxi River Basin, the environmental quality of the study area is divided into four grades: excellent, good, average, and poor (Table 2).

Table 2. Classification of ecological environment assessment results in Liuxi River Basin

Grade	Score	Description of the ecological environment of the Liuxi River Basin
Excellent	(9–10)	High vegetation coverage, reasonable ecological structure, stable ecosystem, strong self-recovery ability, and no damage to natural ecological environment
good	(6–9)	High vegetation coverage, reasonable ecological structure, stable ecosystem, strong self-recovery ability, and basically no damage to natural ecological environment
General	(4–6)	Low vegetation coverage, general ecological structure, relatively unstable ecosystem, self-recovery ability, natural ecological environment is destroyed
Low	(1–4)	Vegetation coverage is low, ecological structure is poor, eco-system is extremely unstable, self-recovery is poor, and natural ecological environment is seriously damaged

3 Results

3.1 Spatial Change Analysis of Ecological Environment

The area with excellent ecological environment quality in Liuxi River Basin is 317 km², which is mainly located upstream, accounting for 13.8%. The ecological environment in this part of the region is basically not damaged, the ecological structure is reasonable and stable, and the ecosystem’s own functions and self-restoration ability are very strong. The area of good quality is 1209 km², accounting for 52.79%, and the ecological structure is basically reasonable and stable. The area of general quality is 700 km², accounting for 30.56%, and the ecological environment is basically damaged, but the eco-system’s own functions and its self-recovery ability is weak; the area with poor quality is 30 km², which is mainly located downstream, accounting for 1.3%. This part of the ecological environment is severely damaged and the ecological structure is unreasonable and therefore, the ecosystem functions and self-recovery capabilities are weak. Generally speaking, the quality of the ecological environment of the river basin is mainly moderate and good. The results of the ecological evaluation of the Liuxi River also show that the environmental quality of the river basin is quite different. The

ecological environment in the Conghua section is better, but it is obviously worse in the middle and lower reaches, and the organic pollution is serious.

3.2 Ecological Time Change Analysis

From the perspective of time change, the proportion of areas with excellent environmental quality increased by 4.46% overall from 1993 to 2018; the proportion of areas with good environmental quality decreased by 4.93% overall, with the maximum specific gravity. The area proportion of general environmental quality continued to rise, but the rate slowed down, with a total increase of 8.42%, which indicated that the area of general environmental quality was getting larger and larger; the percentage of areas with poor environmental quality was decreasing overall, but the overall change was not big, with a total decrease of 3.83%, as shown in Table 3. The areas with good ecological environment quality were an absolute majority, the proportion of area with excellent environmental quality was still rising and the proportion of area with excellent environmental quality was decreasing, so the overall ecological environment of the river basin tended to develop.

Table 3. Changes in ecological environment quality in 1993, 2000, 2010 and 2018

Evaluation grade	Percentage (%)				Change
	years : 1993	2000	2011	2018	
Excellent	8.34	17.57	10.32	13.8	rise4.46%
Good	64.39	52.66	54.54	52.79	decline11.6%
General	22.14	25.36	29.42	30.56	rise8.42%
Low	5.13	4.41	6.72	1.3	decline3.83%

Through comparison of the results of the evaluation of the ecological environment of Liuxi River Basin in 1993, 2000, 2011, and 2018, as shown in Fig. 3, it can be seen clearly that the areas with poor ecological environment in the downstream region increased before 2011. While the upstream Liuxi River Forest Farm, Dalingshan Forest Farm, etc. were mostly with excellent ecological environment quality, and the ecological environment was better. The reason is that the leading industries in the upper reaches of Liuxi River Basin are different from those in the middle and lower reaches. Although the upstream industries have developed rapidly in recent years, they are still dominated by agriculture and tourism. Generally speaking, the degree of pollution of water bodies is positively related to living standards and the local GDP [11]. According to the monitoring data of the environmental protection department from 2009 to 2011, the Liuxi River was classified as Class III when it came out of Conghua District, and it has become inferior to Class V in the middle and lower reaches. The “Southern Daily” and “Guangzhou Daily” and other media repeatedly exposed water pollution events in the Liuxi River. However, the situation was different since 2018, the environmental quality of the downstream in Baiyun and Huadu section have obviously improved, which showed that the ecological environment downstream showed a trend of

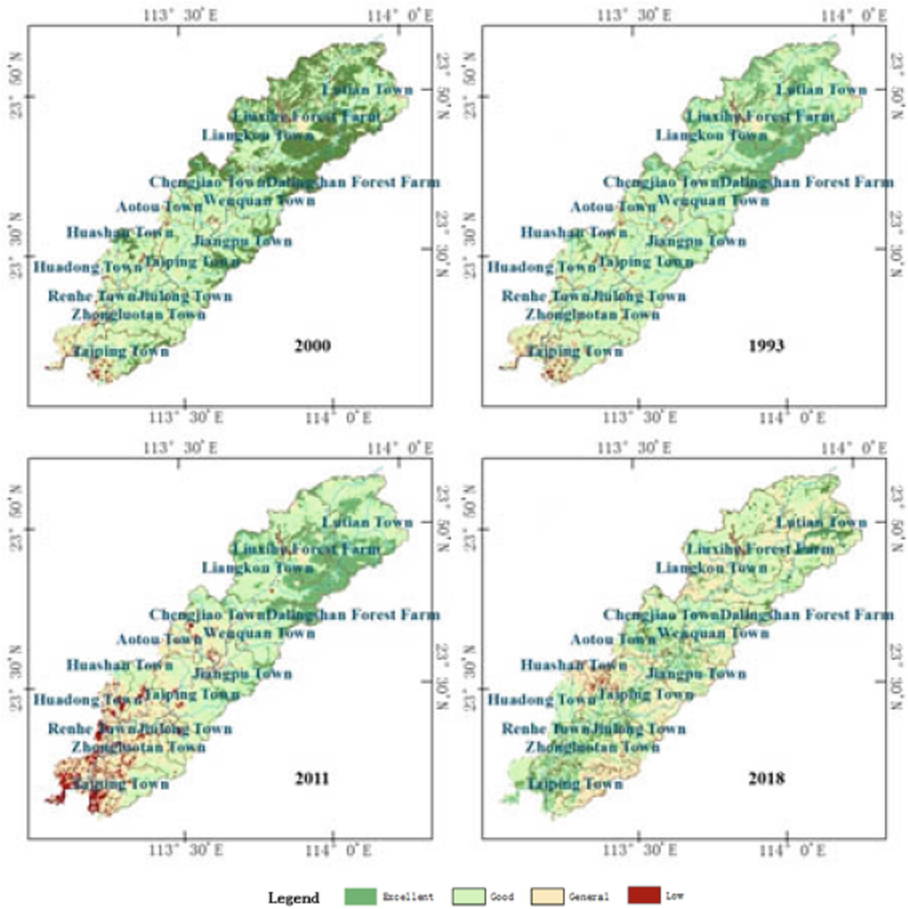


Fig. 3. Eco-environment assessment results of Liuxi River Basin in 1993, 2000, 2011, and 2018

improving. According to the information released by the Guangdong Province on the water quality of key rivers in the fourth year of 2018, the water quality of the Baiyun section of Liuxi River has improved. In the meantime, the quality of the ecological environment of upstream has declined.

3.3 Analysis of Driving Factors of Ecological Environment Change

Analyze the driving factors in terms of land use change, leading industries, and population changes. According to the land use classification results of this study, in terms of construction land, since 2013, the construction land in Taihe Town and Baiyun District has increased rapidly. Due to the development of urbanization and the increase in construction land, the ecological environment quality in the southeast of Baiyun District has declined. In Huashan Town and Huadu Town of Huadu District, the area of cultivated land has decreased significantly, converted into construction land, which has

led to a decline in the quality of the ecological environment in this region. The forest land has not changed significantly from 1993 to 2018. It can be seen that forest land is not the main factor affecting the ecological environment of the river basin. In terms of industries, because the middle and lower reaches are dominated by industries and agriculture, and the upper reaches are dominated by tourism, the ecological environment of the lower and middle reaches is generally worse than the upper reaches. From the perspective of the entire river basin, the middle and upper reaches are most affected by domestic pollution. The lower reaches of the Liuxi River are most affected by industrial pollution [12]. The reasons for the deterioration of the upstream ecological environment in recent years are mainly rapid population growth and increased pollution. This year, the upstream ecological environment has deteriorated. In recent years, the total resident population of forest farms, Lutian Town and Liangkou Town in the upper reaches of the river basin has increased to more than 70,000, resulting in a significant increase in domestic sewage and garbage discharged by residents [13]; the direct cause of the impact on the ecological environment of the river basin is the delayed construction of sewage treatment facilities and regional soil and water loss caused by vegetation destruction. The main source is the unreasonable industrial structure and layout of the river basin [14]. The upstream region has good agricultural development conditions and superior tourism resources. It mainly develops agriculture and tourism, while the middle and lower reaches should strictly restrict the development of industries and other organic pollution industries. Eco-tourism and characteristic agriculture for its economic development should be focused on [15], in order to seek a balance between development and protection.

4 Conclusion

This study takes the Liuxi River Basin as the research area, and fully understands the selection of indicators for eco-environmental assessment and the concepts of each influencing factor and selects the vegetation coverage, DEM, land use, slope index, and soil index as the five impact factors to study the current status of the ecological environment in Liuxi River Basin and its ecological environment change trends and characteristics in the past 25 years. The following conclusions are drawn:

- (1) From the perspective of spatial distribution, the area of the ecological environment with excellent water quality in 2018 is mainly located upstream, accounting for 13.8% of the total area, and the area with good evaluation quality accounts for 52.79%. In general, the assessed ecological environment of the Liuxi River is dominated by areas with general and good conditions. The reason that the quality of the environment in the lower reaches of the river is generally worse than that of the middle and upper reaches is that their leading industries are different. The leading industries of the middle and upper reaches are mainly tourism, while those of the downstream areas are mainly industries and agriculture.
- (2) In terms of time change, the proportion of the areas with excellent environmental quality in each year increased by 13.8%; the proportion of the areas with good environmental quality decreased by 11.6%; the proportion of the areas with

general environmental quality continued to rise but the rising has slowed down, with a total increase of 8.42%; the area with poor environmental quality declined, but the overall change was not big. The excellent and good ecological environment quality of the basin has an absolute advantage and is still improving, and the proportion of area with general and poor environment quality are declined in the meantime, so the overall ecological environment of the basin is developing.

- (3) The areas with poor ecological environment in the downstream region increased before 2011. The reason is that the reduction of cultivated land and construction land in the lower reaches has increased since 2013. Since 2018, the area with poor environment quality in the lower reaches of the basin has gradually decreased, which indicates the ecological environment is better and better. Besides, the overall environmental quality of the upper reaches of the basin in 2018 has suffered due to the increase in the total population of the upper reaches.

Acknowledgments. This research is jointly supported by GDAS' Project of Science and Technology Development (2016GDASRC-0211, 2017GDASCX-0601, 2018GDASCX-0403), duced Talents Team of Southern Marine Science and Engineering Guangdong Laboratory (GML2019ZD0301) and 2019 science and Technology Innovation Project of Provincial Special Fund for Economic Development (2019B1).

References

1. LiuPang, R.C., Zongming, W.: Nanchong River Natural ecological environment quality evaluation of remote sensing. *J. Appl. Ecol.* **29**(10), 3348–3350 (2018)
2. Wang, L., Zhang, J., Chen, W., et al.: Spatiotemporal Manas river basin ecological environment quality points different evaluation. *Arid Study Area* 1–10 (2019)
3. Xu, H.: Typical red soil erosion dynamic change of the surface area of the South bare soil analysis-taking Fujian Ting County as an example. *Geogr. Sci.* **33**(4), 489–496 (2013)
4. Zhao, Y., Zhang, L.: Fragile ecology quantitative assessment method. *Geogr. Sci.* **18**(1), 73–79 (1998)
5. Lai, Z., Xia, S., Cheng, J.: Research on application model of high-resolution remote sensing satellite data in urban ecological environment assessment. *Prog. Geogr. Sci.* **19**(4), 361–364 (2000)
6. Zhang, Y., Yuan, J., Liu, B.: Progress vegetation cover and management factor in the soil erosion prediction model. *J. Appl. Ecol.* **13**, 1033–1036 (2002)
7. Zhang, W., Xie, Y., Liu, B.: China erosivity spatial variation characteristics. *J. Mt. Sci.* **21**(1), 33–40 (2003)
8. Yang, C.J., Liu, J., et al.: Remote sensing and GIS support China reforestation project at the Grassland. *J. Remote Sens.* **6**(3), 206–210 (2002)
9. Gong, C., Chen, Q., Yin, Q., et al.: Remote sensing research base quality evaluation of coastal environment- to Shanghai-Nanhui East Beach as an example. *Mar. Environ. Sci.* **30**(5), 712–718 (2011)
10. Li, H., Shi, Z., Guo, Y.: Evaluation of ecological environment quality in Fujian Province based on remote sensing and GIS technology. *Remote Sens. Technol. Appl.* **21**(1), 49–54 (2006)

11. Zhang, Y.: Study on the water quality change law of Conghua section of Liuxi River. *J. Eco-Environ.* **21**(11), 1902–1904 (2012)
12. Chen, Q.: Impact of human activities on eutrophication of Liuxihe Reservoir in the past 50 years. Jinan University, Guangzhou (2014)
13. Chen, X.: Study on legislation of local watershed management—taking legislation of Liuxi River Managementing Guangzhou as an example. Guangdong University of Foreign Studies, Guangzhou (2013)
14. Chen, J., Wu, E.: Water resources protection of Liuxi River for 20 years. *Guangzhou Environ. Sci.* **17**(3), 41–42 (2002)
15. Yang, Z., Gao, L., Chen, J., et al.: Based on the geochemical characteristics of the river riparian zone-groundwater interaction boundary identification-taking Guangzhou flow River. *Sci. Environ.* **39**(6), 1843–1847 (2019)