Ecological Environment Changes of Mining Areas Around Nansi Lake With Remote Sensing Monitoring

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Research Article

Keywords: Nansi lake, Coal mining, Mine ecological environment, Remote sensing monitoring, Environmental change

Posted Date: February 16th, 2021

DOI: https://doi.org/10.21203/rs.3.rs-186720/v1

Version of Record: A version of this preprint was published at Environmental Science and Pollution Research on April 12th, 2021. See the published version at https://doi.org/10.1007/s11356-021-13849-y.

Ecological environment changes of mining areas around Nansi lake with remote sensing monitoring

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Abstract Underground mining activity has existed for more than 100 years in Nansi lake. Coal mining not only plays a supporting role in local social and economic development but also has a significant impact on the ecological environment in the region. Landsat series remote sensing data (1988~2019) are used to research the impact of coal mining on the ecological environment in Nansi lake. Then Support Vector Machine (SVM) classifier is applied to extract the water area of the upstream lake from 1988 to 2019, and ecological environment and spatiotemporal variation characteristics are analyzed by Remote Sensing Ecology Index (RSEI). The results illustrate that the water area change is associated with annual precipitation. Compared with 2009, the ecological quality of the lake is worse in 2019, and then the reason for this change is due to large-scale underground mining. Therefore, the coal mines from the natural reserve may be closed or limited to the mining boundary for protecting the lake's ecological environment.

Keywords Nansi lake; Coal mining; Mine ecological environment; Remote sensing monitoring; Environmental change

Introduction

Nansi lake is located in the southwest of Shandong Province, China (34°27′N to 35°20′N and 116°34′E to 117°24′E), which is composed of Nanyang lake, Dushan lake, Zhaoyang lake, and Weishan lake. Nansi lake is the largest freshwater lake in Shandong Province and the sixth-largest freshwater lake in China (the water area is 1266 km^2). Also, the northern terrain of Nansi lake is higher than the southern terrain, the length is 125 km from north to south, the width is 5.6 to 30 km from east to west, the average water depth is 1.5m, and the maximum water depth is 6m. Nansi lake lies within a warm temperate humid monsoon climate (Liang 2014), which benefits a diversity of plant and animal species including 539 species of vascular plants, 337 species of vertebrates, and 221 species of birds in the lake area. Moreover, the lake area is an important habitat and breeding place for many rare and endangered birds, as well as an important migration and resting place for migratory birds in spring and autumn. Moreover, Nansi lake was established as a provincial nature reserve by the government in 2003, and then the government adjusted the scope and functional areas of the Nansi lake provincial nature reserve in 2019 (Fig. 1). The current area is larger than the original after adjustment, the total area is 1116.51 km^2 and the core zone is 451.15 km^2, which accounts for 40.41% of the total area.

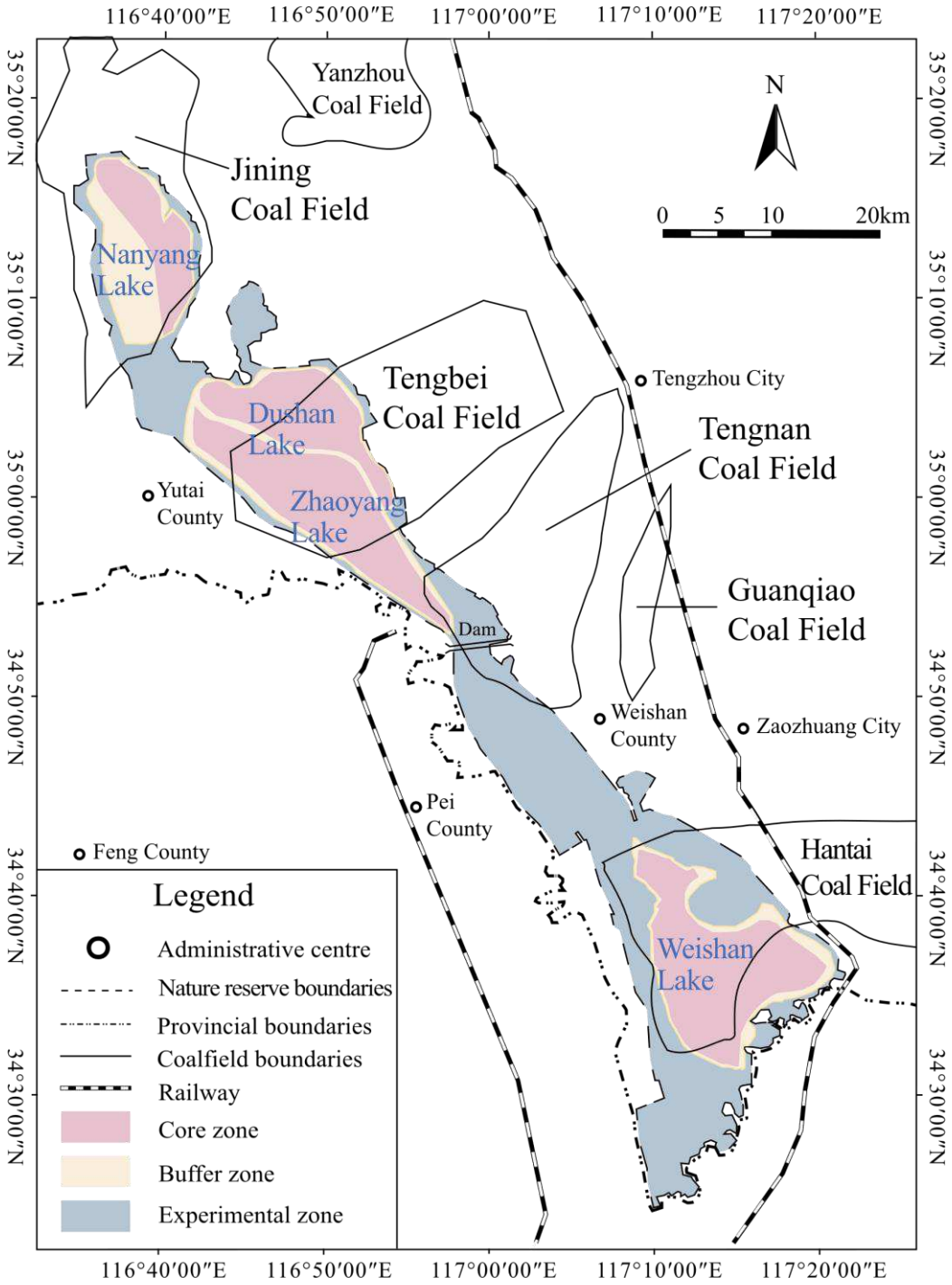

Fig. 1 Distribution of Nansi lake nature reserve and coal resources

Abundant coal resources exist around the Nansi lake area, and people mine coal resources for more than 100 years. In the past two decades, the lake area has been an important energy production base, the coal production accounts for 15% of the total coal production in Shandong Province. The underground mining can destroy the original strata stress balance, which leads to the collapse, fracture, and bending from the bottom to the top. The surface can subside due to the underground mining

influence (Den et al. 2015; Jiang et al. 2019). There is a long history of the impact of surface subsidence on the land environment (Kratzsch 1974; Reddish and Whittaker 1989). However, the research of water ecological environment damage caused by underground mining is insufficient. Most researches believe the two viewpoints: (1) Underground mining can not cause surface water to leak into the mine, and underground mining has no direct impact on surface water; (2) The subsidence caused by mining can increase the water depth, expand the water storage capacity, decrease the speed of sediment siltation, and also benefit for irrigation, shipping, aquaculture, etc. (Ma et al. 2019; Shu 1992; Zhang et al. 2018). The surface subsidence can change the original topography of the lake area and the ecological environment (a non-pollution hazard to the lake area ecology). On the one hand, researchers always concentrate on the safeguard of coal mine and maximum utilization of coal resource and form mature safety measures for underwater mining (Teng et al. 2012). On the other hand, researchers focus on the destruction law of strata (Sui and Xu 2013; Xu and Sui 2013), but they hardly consider the impact of underground mining on the ecological environment. However, environmental supervision departments pay attention to gangue and mine water discharge (Wang et al. 2016) and hardly focus on the relationship between coal mining and the water ecosystem. At present, the ecological effect of coal mining on the environment of Nansi lake is not clear, so it is necessary to research this issue.

The surface subsidence caused by coal mining is a time process, so the impact of mining subsidence on the environment is a cumulative process, which can not be found in a short time. Therefore, the long-term remote sensing data from 1988 to 2019 are used to assess the ecological environment quality of the lake area with the Remote Sensing Ecological Index (RSEI). The cumulative influence of coal mining on the ecological environment can be indirectly reflected. Finally, it provides a quantitative scientific basis for evaluating the impact of coal mining on Nansi lake.

Materials and methods

Research area

Nansi lake is divided into upstream lake and downstream lake by the dam. The research area is located in the upstream lake that is composed of three lakes (Nanyang lake, Dushan lake, and Zhaoyang lake) (Fig. 2). The coal-bearing area in the lake is 1789 km^2, and the average thickness is 11m (Li and Jiang 2003). More than 40 mines exist in Nansi lake after decades of exploration and development, Jining, Tengnan, and Tengbei coal fields are located in the research area.

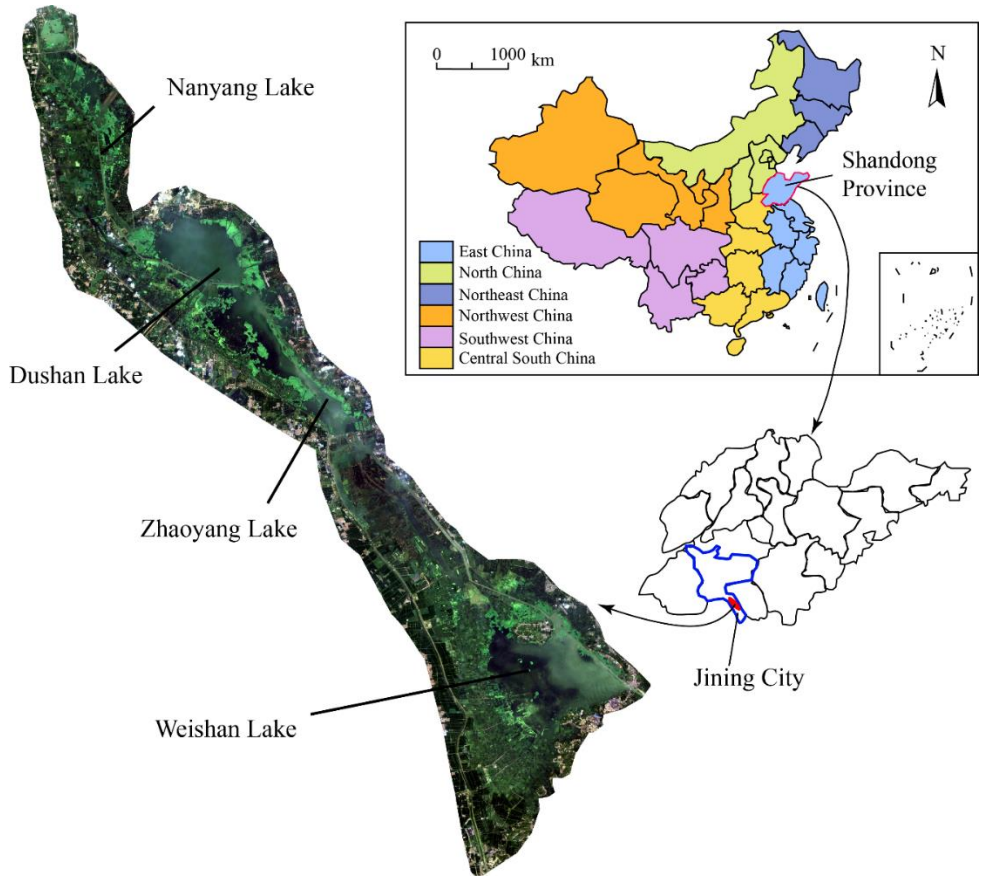

Fig. 2 Location of Nansi Lake (2019 Landsat-8 OLI image)

Data acquisition and preprocessing

The main data sources are the Landsat series of remote sensing images, which are freely obtained from the U.S. Geological Survey (https://earthexplorer.usgs.gov/), Landsat-5 TM data are from 1988~2005, 2010, and 2011; Landsat-7 ETM data are from 2006~2009; Landsat-8 OLI/TIRS data are from 2012, and 2013~2019. The time of these images is selected in August or September due to less cloud cover and fair weather. Generally, the recent images (2019) are chosen to be the registration benchmark, and the accuracy is controlled within 0.5 pixels. Finally, pretreatments such as radiometric calibration, atmospheric correction, and image cropping are implemented.

Extraction of water area

Support Vector Machine (SVM) classifier is used to extract the upstream lake water area of Nansi lake. Compared with other automatic extraction methods of single band threshold, the SVM classification method can sufficiently apply the abundant spectral information and geometric texture

information, and the extraction accuracy of the water body is higher than that of other methods. SVM is a kind of generalized linear classifier with a binary classification of supervised learning (Gold and Sollich 2003). It is widely used in remote sensing image classification and other information extraction. The classification principle is that apply a hyperplane as the decision boundary, which can achieve correct classification and maximize the classification interval.

The SVM classification method mainly uses two bands of remote sensing data to extract water: (1) the near-infrared band (0.76~0.90 μm), in the strong absorption zone of the water body, which is applied to define the water boundary, and identify the geological structure and landform related to water; (2) the far-infrared band (2.08~2.35 μm), in the strong absorption zone of the water body, the water area appears black in this band. In addition, SVM also combines texture information to distinguish the boundaries of the lake, fish ponds, and paddy fields. The overall accuracy of classification is 85%, and the kappa coefficient (an index to measure the accuracy of classification, it has five different levels to define uniformity, the result is almost perfect between 0.81 and 1.0) is 0.82. This result illustrates SVM is significant and high precision for extracting lake water area.

Construction of Remote Sensing Ecology Index (RSEI)

The Ministry of Environmental Protection of China promulgated the latest revision of the *Technical Criterion for Ecosystem Status Evaluation* (China MEE 2015) in March 2015. The Ecological Index (EI) from this criterion has five evaluating indicators including biological richness, vegetation coverage, water network density, land degradation, and pollution load. The indicators of biological richness, vegetation coverage, water network density can be obtained easily by remote sensing, but the last two indicators are more difficult to gain by remote sensing. Besides, the weights of the five indicators are determined by a human, which has a certain subjective deviation. However, Remote Sensing Ecology Index (RSEI) applies four indicators of greenness, humidity, dryness, and heat to define the weight of each indicator with principal component analysis, and RSEI can avoid human subjective deviation. The greenness is similar to the biological richness, vegetation coverage from the criterion due to the similar calculation method. Humidity is similar to water network density, it can represent not only lakes and rivers but also the humidity of vegetation and soil. Dryness is related to land degradation, so the bare soil can express dryness. The higher value of bare soil shows more serious land degradation. The surface temperature (heat) is related to urban expansion and other

environmental changes.

Remote Sensing Ecological Index (RSEI) applies to perform principal component analysis (PCA) for the four components of wetness (Wet), greenness (FVC), dryness (NDBSI), and heat (LST), and then the first principal component (PC1) is normalized to generate RSEI. PCA is a statistical analysis method in which multiple variables convert to minorities of principal components with dimensionality reduction technology (Du and Fowler 2007). These principal components can reflect most of the information of the original variables, and they are usually expressed as some linear combination of the original variables.

Greenness (FVC)：Fractional Vegetation Cover (FVC) refers to the percentage of the vertical projection area of vegetation on the ground (including leaves, stems, and branches) in a unit area to the total area of the statistical area (Zhou et al. 2006). Therefore, FVC can be used to indicate the greenness:

$$FVC = \frac{NDVI - NDVI_{soil}}{NDVI_{veg} - NDVI_{soil}} \quad (1)$$

$$NDVI = (\rho_{NIR} - \rho_R) / (\rho_{NIR} + \rho_R) \quad (2)$$

where

NDVI- normalized vegetation index; $NDVI_{soil}$- *NDVI* value of bare soil or no vegetation cover area; $NDVI_{veg}$- the *NDVI* value of the vegetation cover area; ρ_{NIR}– spectral reflectance of the near-infrared band; ρ_R– spectral reflectance of the red band

Wetness (Wet)：the wetness index reflects the humidity of water, soil, and vegetation, which is closely related to the ecological environment (Crist 1985; Huang et al. 2002; Todd and Hoffer 1998). The Landsat-5 TM data, Landsat-7 ETM data, and Landsat-8 OLI/TIRS data can be respectively calculated by equation (3), (4), and (5).

$$Wet = 0.0315\rho_B + 0.2021\rho_G + 0.3102\rho_R + 0.1594\rho_{NIR} - 0.6806\rho_{SWIR_1} - 0.6109\rho_{SWIR_2} \quad (3)$$

$$Wet = 0.2626\rho_B + 0.2141\rho_G + 0.0926\rho_R + 0.0656\rho_{NIR} - 0.7629\rho_{SWIR_1} - 0.5388\rho_{SWIR_2} \quad (4)$$

$$Wet = 0.1511\rho_B + 0.1973\rho_G + 0.3283\rho_R + 0.0.3407\rho_{NIR} - 0.7117\rho_{SWIR_1} - 0.4559\rho_{SWIR_2} \quad (5)$$

where

ρ_B- spectral reflectance of the blue band; ρ_G- spectral reflectance of the green band; ρ_R- spectral reflectance of the red band; ρ_{NIR}– spectral reflectance of the near-infrared band; ρ_{SWIR_1}- spectral reflectance of the mid-infrared band; ρ_{SWIR_2}- spectral reflectance of the far-infrared band

Dryness (NDBSI)：the dryness index consists of the average of the building index (IBI) (Xu 2008) and the bare soil index (SI) (Rikimaru et al. 2002)：

$$NDBSI = \frac{IBI + SI}{2} \quad (6)$$

$$IBI = \frac{\frac{2\rho_{SWIR_1}}{\rho_{SWIR_1} + \rho_{NIR}} - \frac{\rho_{NIR}}{\rho_{NIR} + \rho_R} + \frac{\rho_G}{\rho_G + \rho_{SWIR_1}}}{\frac{2\rho_{SWIR_1}}{\rho_{SWIR_1} + \rho_{NIR}} + \frac{\rho_{NIR}}{\rho_{NIR} + \rho_R} + \frac{\rho_G}{\rho_G + \rho_{SWIR_1}}} \quad (7)$$

$$SI = \frac{(\rho_{SWIR_1} + \rho_R) - (\rho_{NIR} + \rho_B)}{(\rho_{SWIR_1} + \rho_R) + (\rho_{NIR} + \rho_B)} \quad (8)$$

Where

ρ_B- spectral reflectance of the blue band; ρ_G- spectral reflectance of the green band; ρ_R- spectral reflectance of the red band; ρ_{NIR}– spectral reflectance of the near-infrared band; ρ_{SWIR_1}- spectral reflectance of the mid-infrared band

Heat (LST)：The heat index is expressed by the land surface temperature (LST), and its calculation model (Nichol 2005) is following：

$$LST = T / \left[1 + \left(\lambda T / \rho\right) \ln \varepsilon\right] \quad (9)$$

$$T = K_2 / \ln\left(K_1 / L_{TIR} + 1\right) \quad (10)$$

where

LST- land surface temperature; *T*- temperature of the sensor, λ- central wavelength of the thermal infrared band; ρ- calculation parameter (1.438×10^{-2}m·K); ε- land surface emissivity (it can be calculated by NDVI with Sobrino's model) (Sobrino et al. 2004); L_{TIR}- the radiation of TM, ETM, and TIRS thermal infrared band; K_1 and K_2- calibration parameters

Because the dimensions of the four indicators are not uniform, these indicators should be standardized before the principal component analysis (Fig. 3). The RSEI result shows the larger value, the better the ecological quality.

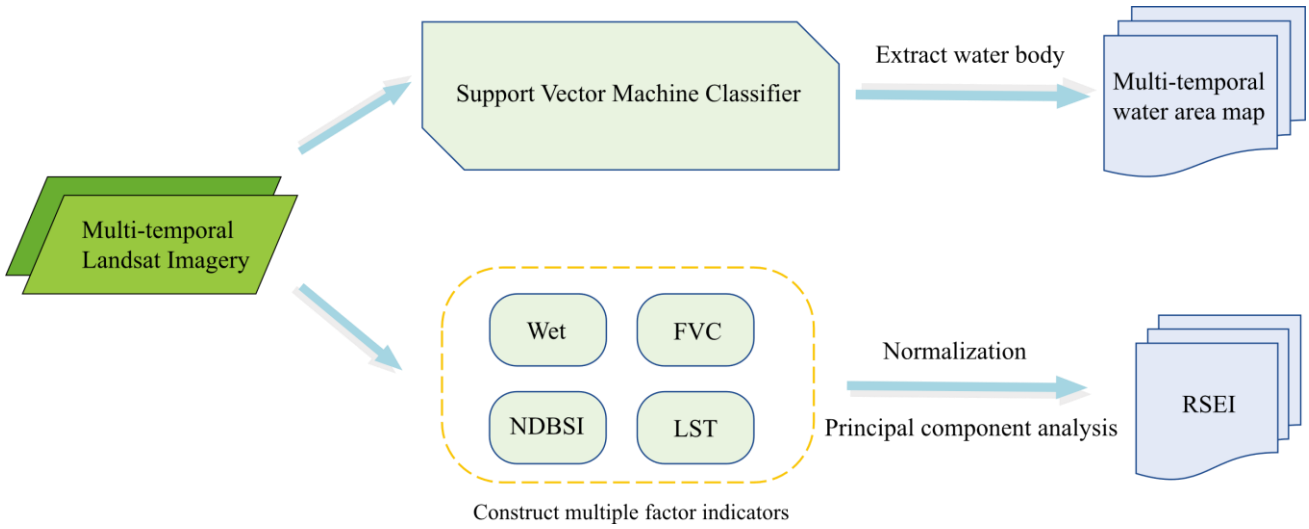

Fig. 3 Research method route

Results and discussion

Water area change

The SVM classification method was used to extract the water area of upstream Nansi lake from 1988 to 2019 (Fig. 4). According to the change information of remote sensing monitoring, the water areas (blue parts) in 1988 and 2000 were extremely smaller than that of other years (Fig. 4a and 4e), Nanyang and Zhaoyang lakes almost dried up due to severe drought from 1987 to 1989 and 2000 to 2002 (Meng and Dong 2019). The water level of the upstream lake dropped to the lowest level in history, and the lake water basically dried up. The water areas decreased every year and appeared

fragmented shapes around the lake boundary.

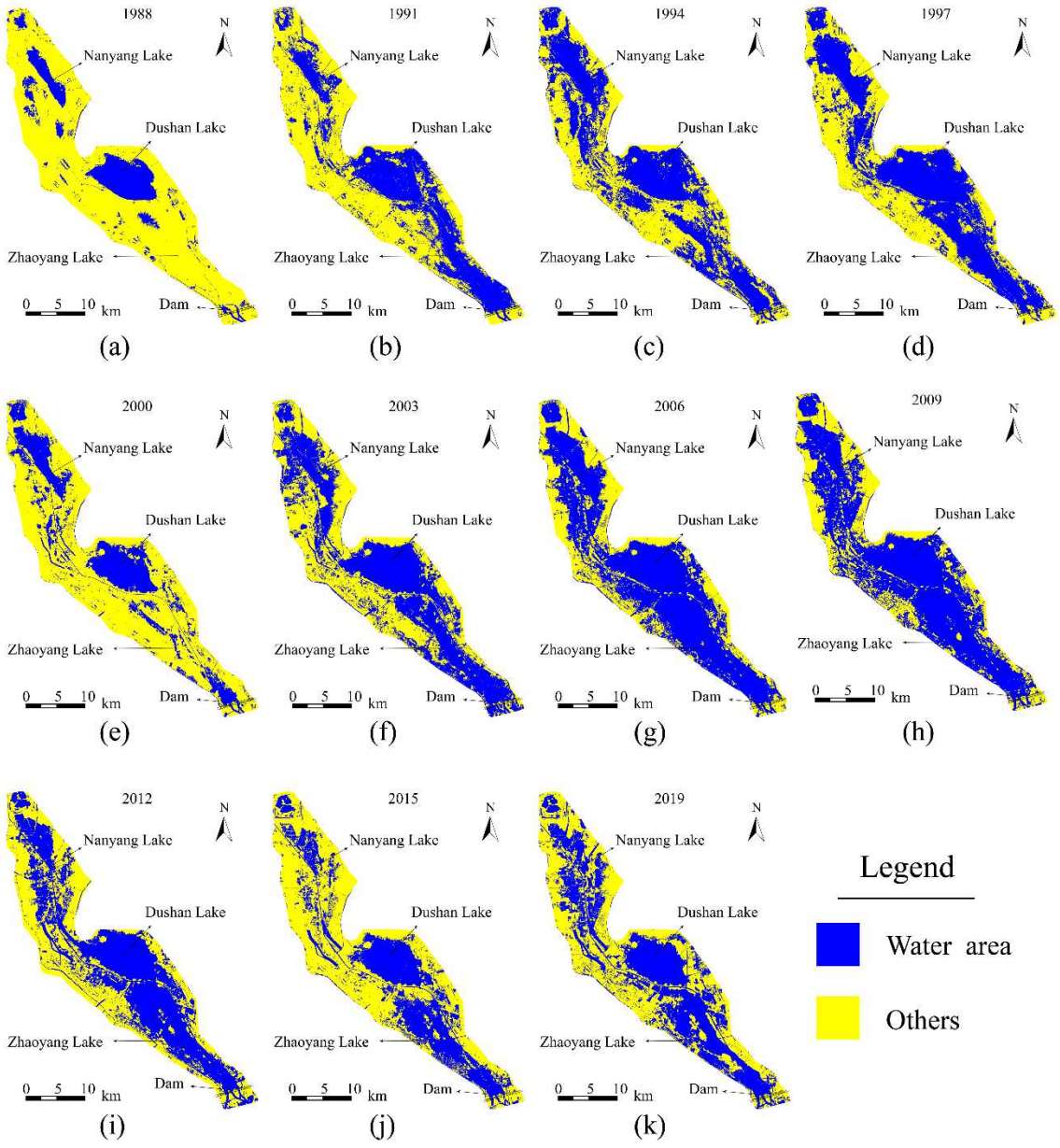

Fig. 4 Variation characteristics of the upstream Nansi lake

In addition, extracted water area data and average precipitation (from 1988 to 2019) were used to objectively assess the water area change. The trends of water area change (red line) and average precipitation (blue line) are identical in Fig. 5. This result illustrates that the trend of water area change is consistent with that of average precipitation in the last thirty years.

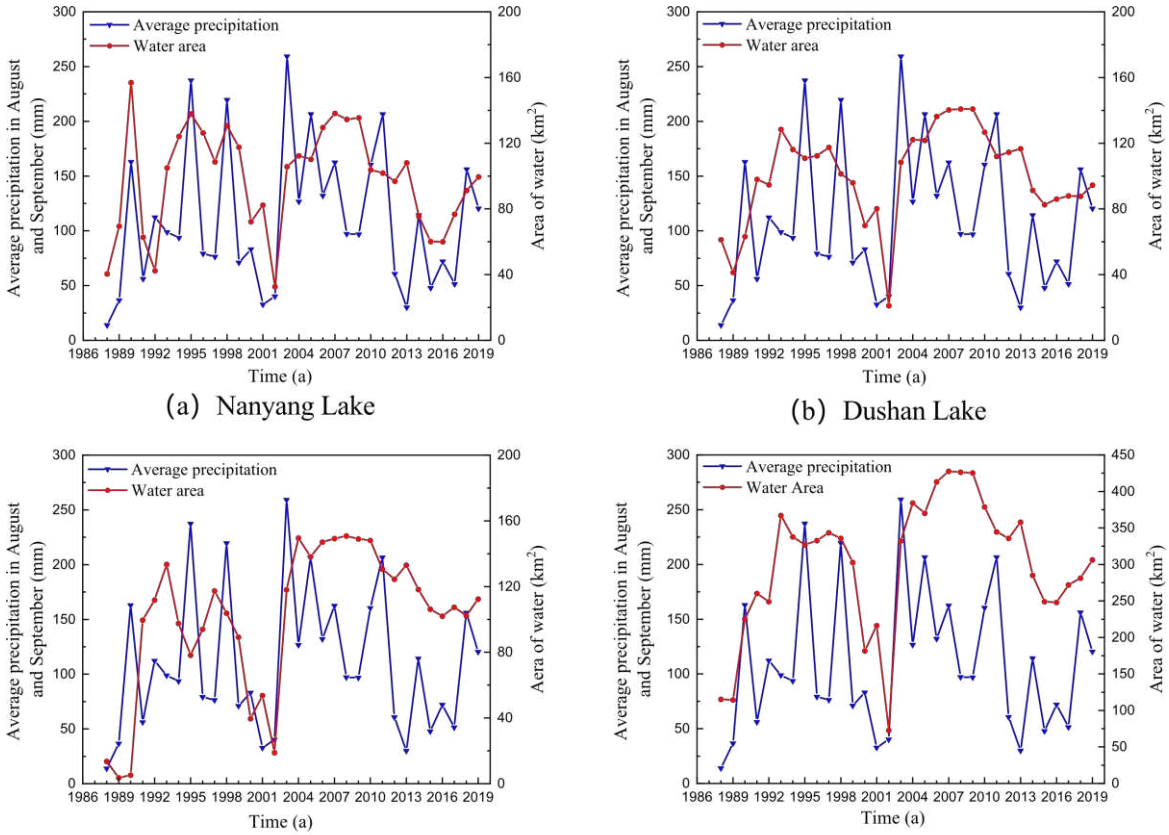

Fig. 5 The trends of water area and average precipitation

Therefore, it seems that underground mining in Jining and Tengbei coal fields has barely influence on the lake water area, instead, the water area change is related to the precipitation. However, the water area may be affected by the extension of underground mining to the lake. The total overlapping area of these two coal fields and the lake is 398km^2, which is about 66% of the lake area. According to estimate, the subsidence volume of the lake bottom will be 1.94×10^9 m^3 after accomplish mining of two coal fields, but the lake storage capacity is only 9.03×10^8 m^3, namely that most of the lake water will flow into the subsidence area, and the shallow water may no longer exist. Finally, this phenomenon can make a significant reduction in the water area.

Analysis of RSEI indexes

According to the weights of four RSEI indexes (Table 1), the average RSEI increased from 0.583 to 0.632 between 1988 and 2009 (increased by 8.4%). However, the average RSEI decreased from 0.632 to 0.584 between 2009 and 2019 (decreased by 7.59%). RSEI appears a trend of the slow rise and then a sharp decline in this research area. This trend illustrates that the ecological environment

gets better and then gets worse. Moreover, PC1 loads of wet and FVC have a positive influence on the ecological environment, but PC1 loads of NDBSI and LST have a negative influence on the ecological environment (positive number: beneficial; negative number: harmful). The contributions of wet and FVC show a reduced trend, but that of NDBSI and LST appear to a rising trend. These trends illustrate vegetation coverage and construction land have a significant effect on the ecological environment, and then the decline of vegetation coverage and increase of construction land make the ecological environment worse.

Table 1 Statistics of factor indicators and Remote Sensing Ecological Index

Indexes	1988		1998		2009		2019	
	Average	PC1 load	Average	PC1 load	Average	PC1 load	Average	PC1 load
Wet	0.546	0.182	0.679	0.179	0.630	0.181	0.662	0.153
FVC	0.719	0.574	0.747	0.581	0.729	0.563	0.691	0.461
NDBSI	0.568	-0.551	0.560	-0.543	0.493	-0.572	0.366	-0.669
LST	0.338	-0.412	0.388	-0.402	0.433	-0.542	0.405	-0.631
RESI	0.583		0.587		0.632		0.584	

Dynamic changes of ecological environment

RSEI is divided into five levels for the change analysis of ecological environment: Poor (0~0.2), Fair (0.2~0.4), Moderate (0.4~0.6), Good (0.6-0.8), Excellent (0.8~1.0) (Table 2).

Table 2 Ecological environment classification

RSEI Level	Description
Poor (0~0.2)	Severe natural ecological conditions, prominent ecological environmental problems, and extremely fragile ecological functions.
Fair (0.2~0.4)	Less vegetation coverage, fewer species, obvious ecological environmental problems, fragile ecological functions, and obvious factors limiting human activities.

Moderate (0.4~0.6)	Moderate vegetation coverage, general biodiversity, general natural ecological conditions, certain ecological environmental problems, and relatively fragile ecological functions.
Good (0.6~0.8)	Relatively high vegetation coverage, relatively abundant biodiversity, relatively good natural ecological condition, relatively stable ecological function, and certain ecological environmental problems.
Excellent（0.8~1.0）	High vegetation coverage, relatively abundant biodiversity, superior natural ecological condition, high ecosystem carrying capacity, stable ecosystem, and strong self-regulation ability.

According to the information of RESI change, the ecological environment of the east is generally worse than that of the west from 1988 to 2019 (Fig. 6). The main reason may low mountains and hills and serious soil erosion exist in the northeast (Ge et al. 2012). In the recent thirty years, the ecological environment of the northeast is better than before, which is related to afforestation and other beneficial activities of improving soil erosion. In addition, underground mining activities exist in the coal fields of the southeast for many years (Fig. 7), which can make surface subsidence of some areas. The surface subsidence can reduce the original covers of farmland, grassland, and woodland (Liang 2014; Meng and Dong 2019), and then cause a series of environmental problems. The level of ecological environment changes from excellent to fair or poor, ecological environmental problems and ecological function are more fragile. The ecological environment of the western area is better than that of the eastern area, but some poor areas appear an expansion trend in the western area. This phenomenon is probably caused by an increase in urban construction land (Liu et al. 2020).

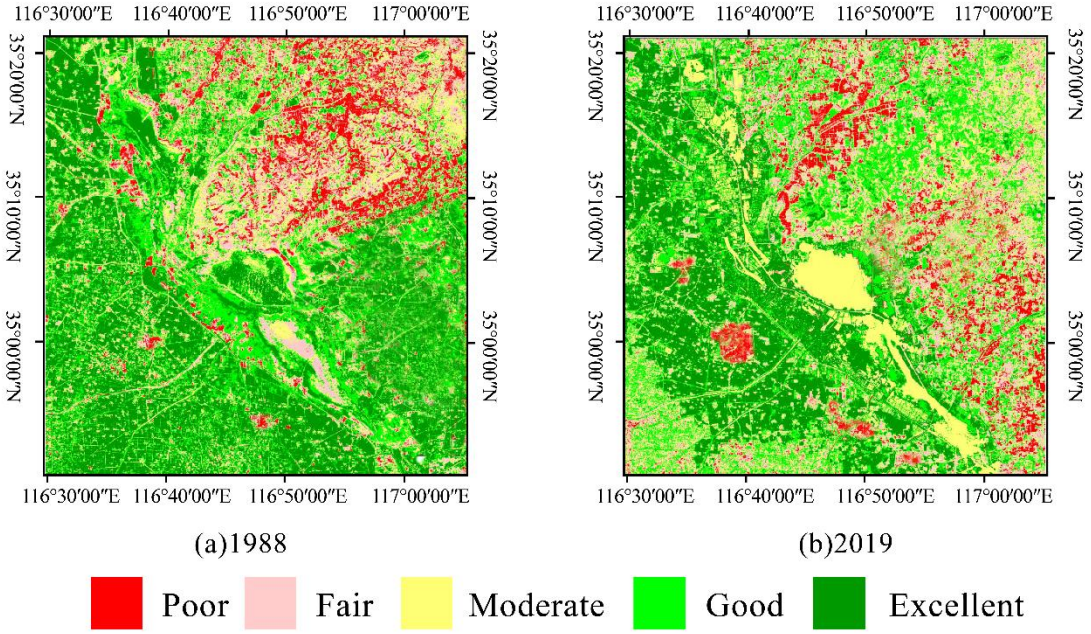

Fig. 6 RSEI classification of the upstream Nansi lake

Moreover, the ecological environment level of the lake grades from excellent or good to moderate. Underground mining activity is probably the main reason, three mines including Binhu, Xin'an, and Huxi mines (Fig. 7 and Table 3) implement mining activity under the lake. Therefore, mining activity is detrimental to biodiversity, ecological environment, and ecological function.

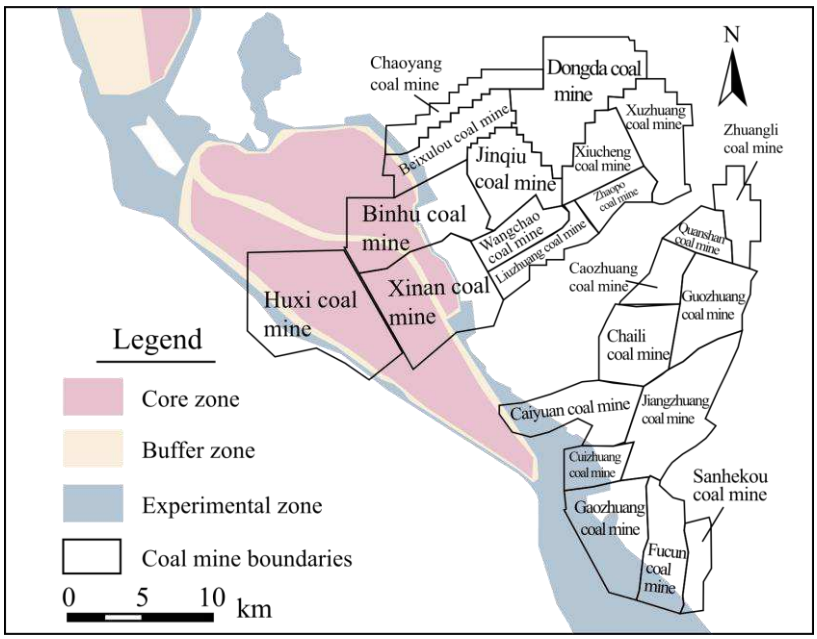

Fig. 7 Distribution of mines around the upstream Nansi lake

Table 3 Overview of some mines in the research area

Coal Field	Mine	Location relationship with the lake	Production time (year)	Design production capacity (1×10^4 t/year)
Tengbei	Binhu	lakeside and under the lake	2005	1.10
	Xin'an	lakeside and under the lake	1998	3.53
	Huxi	lakeside and under the lake	2001	0.90
	Beixulou	lakeside and under the lake	1996	0.45
	Chaoyang	lakeside	2003	0.45
	Jinqiu	lakeside	2005	0.45
	Wangchao	lakeside	1994	0.30
	Liuzhuang	lakeside	1993	0.60
	Dongda	other	1995	0.45
	Zhaopo	other	1991	0.50
Tengbei	Cuizhuang	lakeside and under the lake	1993	0.60
	Gaozhaung	lakeside and under the lake	1997	3.20
	Fucun	lakeside and under the lake	1998	2.70
	Sanhekou	lakeside and under the lake	1992	0.60
	Caiyuan	lakeside and under the lake	1982	0.30
	Jiangzhuang	lakeside	1988	1.50
	Chaili	lakeside	1964	1.80

The RSEI result of 2019 is less than that of other years in the excellent level, and then the maximum appears in the moderate level, which is higher than that of other years (Fig. 8). In addition, the excellent level area decreases by 18.0% from 1988 to 2019. The good level area increases significantly in 2009 but decreases by 103.713 km^2 in 2019 compared to 2009 (Table 4). The trend of the moderate level area is similar to the good level, the decreased area is inapparent in 2019. The fair level area is maximum in 1998, and the area of 2019 is basically similar to 1988. The trend of poor

level area decreases from 1988 to 2009, and then the area increases by 101.782 km^2 between 2009 and 2019. Compared with 2009, the ecological quality of 2019 is worse. The reason for this change is due to large-scale underground mining.

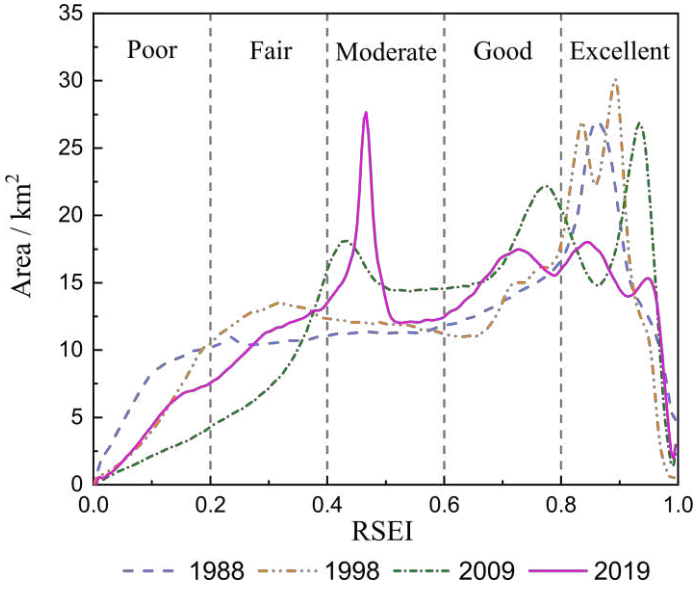

Fig. 8 RSEI variation of the upstream Nansi lake

Table 4 Area of each ecological level and proportion

RSEI Level	1988		1998		2009		2019	
	Area (km^2)	Proportion (%)	Area (km^2)	Proportion (%)	Area (km^2)	Proportion (%)	Area (km^2)	Proportion (%)
Poor (0~0.2)	352.660	11.558	231.710	7.594	106.156	3.479	207.938	6.815
Fair (0.2~0.4)	540.141	17.703	641.314	21.019	408.193	13.379	551.358	18.071
Moderate (0.4~0.6)	575.793	18.872	606.455	19.877	794.147	26.028	772.188	25.308
Good (0.6~0.8)	693.689	22.736	686.372	22.496	894.654	29.322	790.941	25.923
Excellent (0.8~1.0)	888.834	29.131	885.265	29.014	847.967	27.792	728.692	23.883

Conclusions

The remote sensing is applied to monitor the change of ecological environment in Nansi lake, and the lake area is extracted by the SVM classifier of spectral and geometric texture information.

Moreover, four indexes of RSEI (greenness, humidity, dryness, and heat) are used to assess ecological environment quality with the PCA analysis method, which can avoid artificial subjective defects.

The change of the lake water area has little relation with underground mining but is related to the annual precipitation. According to estimate, the subsidence volume of the lake bottom will be 1.94×10^9 m^3 after accomplish mining of Tengnan and Tengbei coal fields, but the lake storage capacity is only 9.03×10^8 m^3, namely that most of the lake water will flow into the subsidence area, and the shallow water may no longer exist.

The area of deteriorating ecological environment is located in Tengnan and Tengbei coal fields. Vegetation coverage decreases (reduction of greenness and wetness; increase of dryness and heat) due to surface subsidence, gangue, and drainage. On the one hand, the deteriorating ecological quality of the lake area is mainly affected by mining activities including Huxi, Xin'an, and Binhu coal mines. The deteriorating ecological quality of the non-lake area is mostly influenced by Jinqiu, Wangchao, and Dongda coal mines. On the other hand, the area of improved ecological environment is located in the northeastern hilly area, which attributes the success to afforestation and other beneficial activities of improving soil erosion.

Finally, coal mines need to apply more environmentally friendly mining method for protecting the lake ecological environment, and actively participate in ecological restoration. Moreover, the coal mines from the natural reserve may be closed or limited to the mining boundary.

Acknowledgments

The authors are grateful to the Alexander von Humboldt Foundation for supporting this research team (CHN/1101176STP), National Research and Development Project (2016YFC0501105), and China Coal Technology & Engineering Group Project (2018-TD-MS052).

Ethical Approval

The manuscript does not involve animal and human experiments, so ethical approval is not applicable.

Consent to Participate

All the authors agree to participate in this research.

Consent to Publish

All the authors agree to publish the manuscript research.

Authors Contributions

Hu Liu: writing, calculation, and visualization

Yan Jiang: funding support, writing- reviewing and editing

Rafal Misa: model research, modification of the text, and discussion

Junhai Gao: project support, and scientific advice

Mingyu Xia: remote sensing data processing

Axel Preusse: providing scientific advice and reviewing

Anton Sroka: providing scientific advice and reviewing

Yue Jiang: providing research plan, remote sensing data processing, writing- reviewing and editing

Funding

This research work was financially supported by the Alexander von Humboldt Foundation (CHN/1101176STP), National Research and Development Project (2016YFC0501105), and China Coal Technology & Engineering Group Project (2018-TD-MS052).

Availability of data and materials

All data generated or analysed during this study are included in this manuscript.

Conflict of Interest

The authors declare no conflict of interest.

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Figures

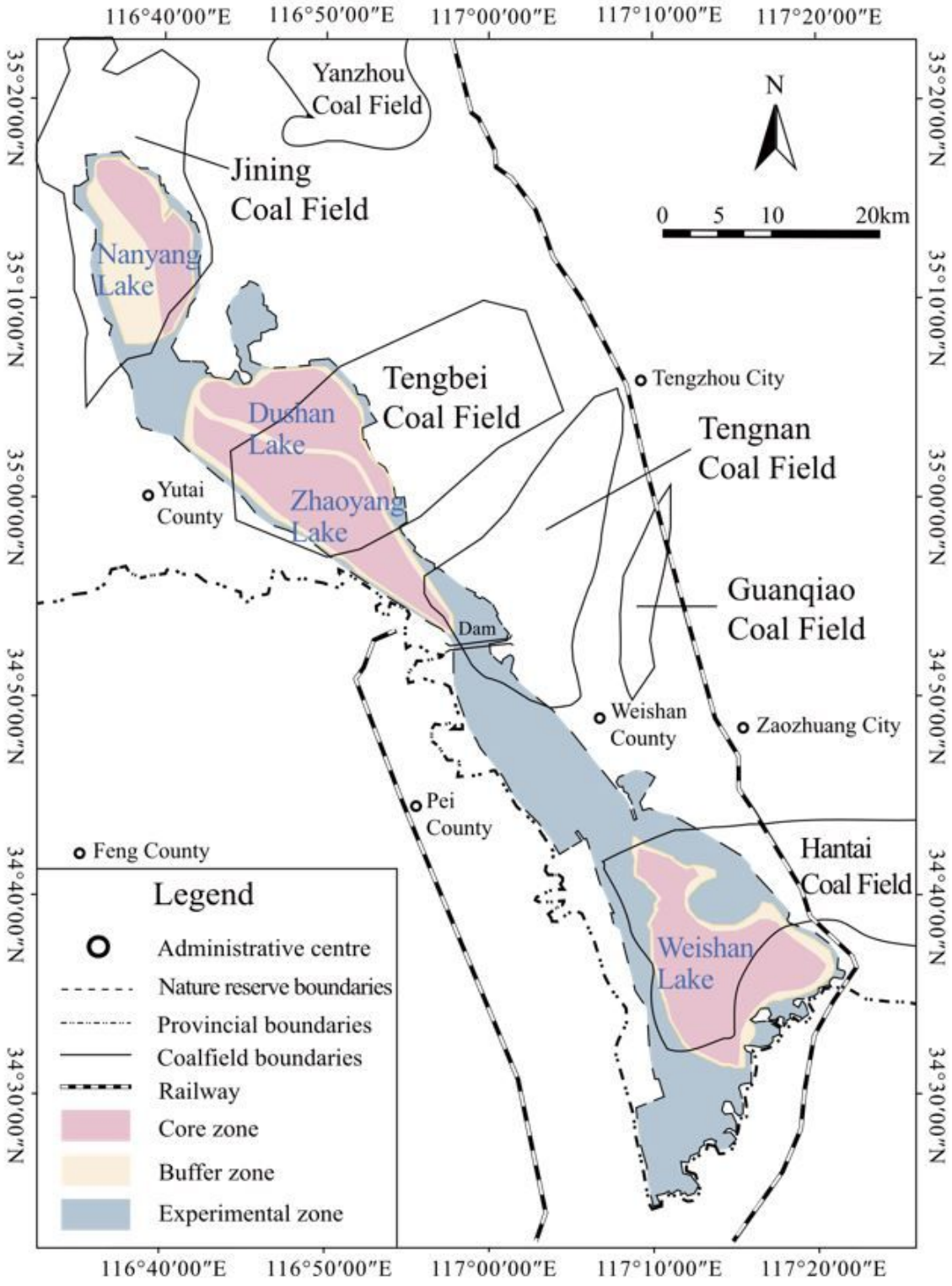

Figure 1

Distribution of Nansi lake nature reserve and coal resources Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its

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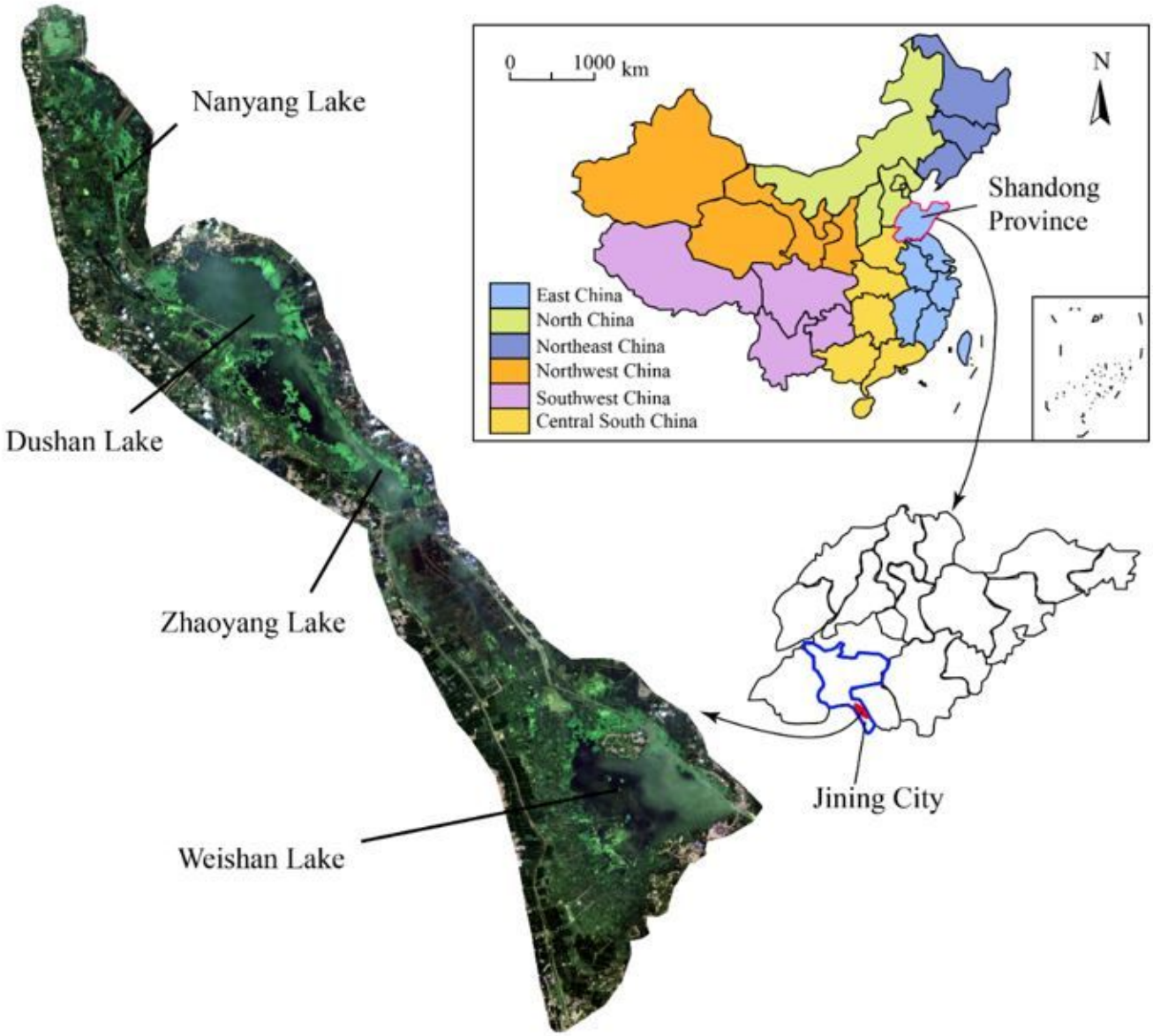

Figure 2

Location of Nansi Lake (2019 Landsat-8 OLI image) Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

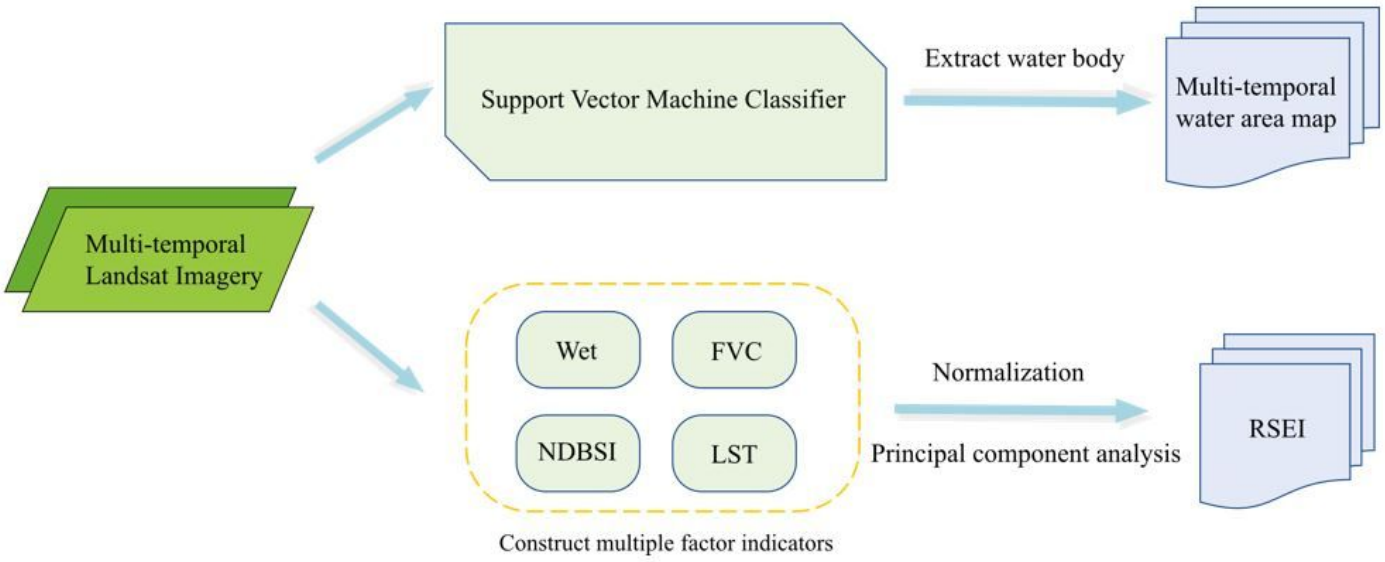

Figure 3

Research method route

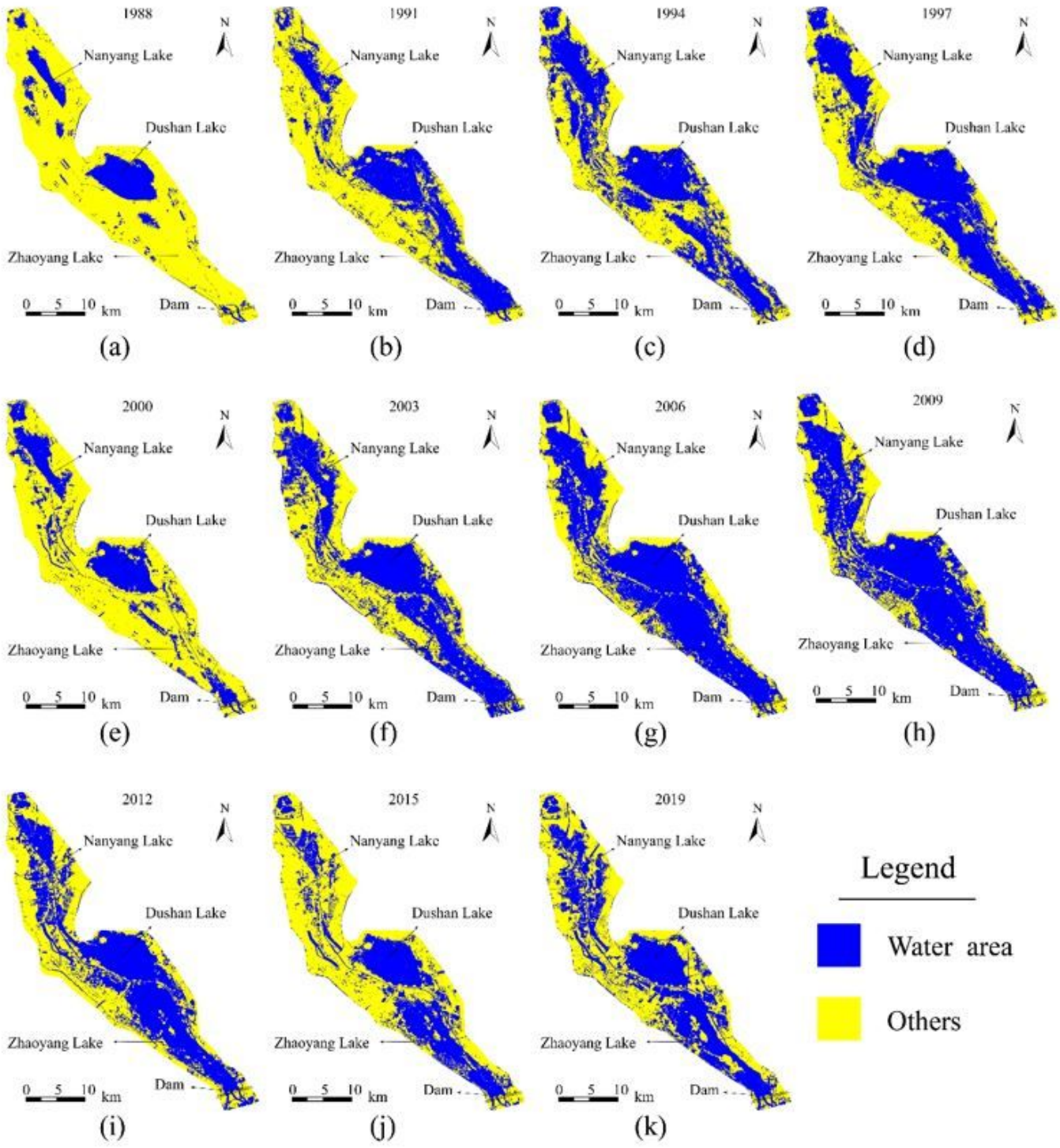

Figure 4

Variation characteristics of the upstream Nansi lake Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

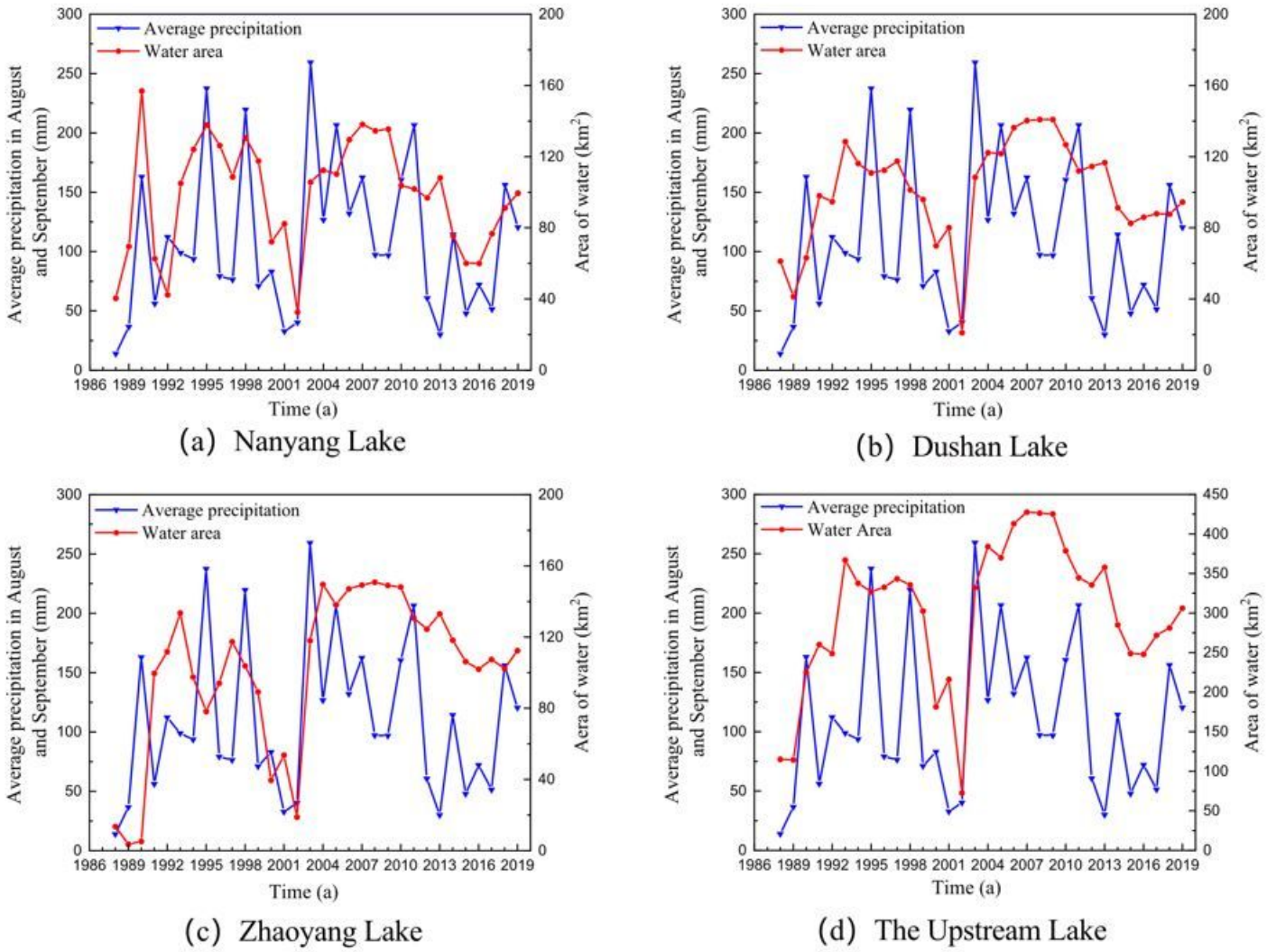

Figure 5

The trends of water area and average precipitation

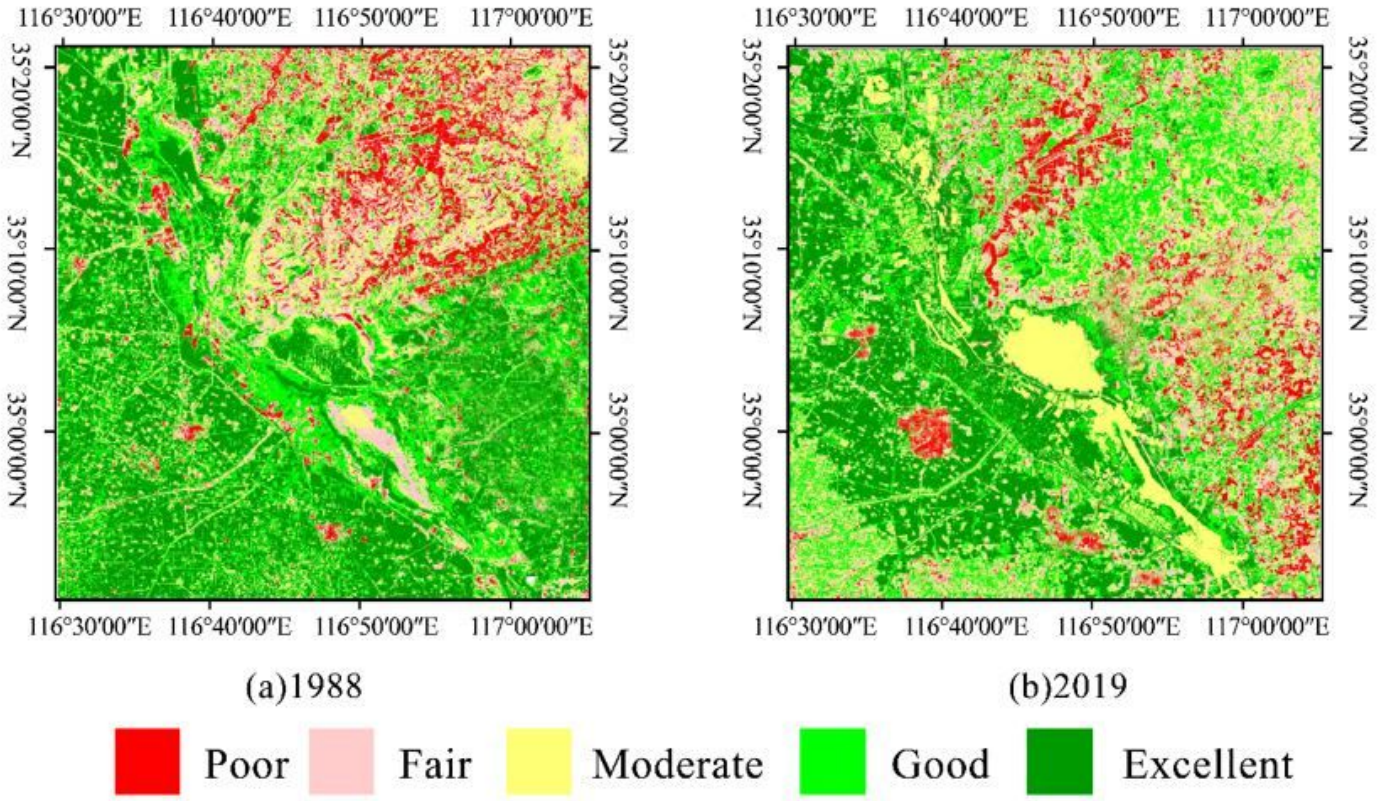

Figure 6

RSEI classification of the upstream Nansi lake Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

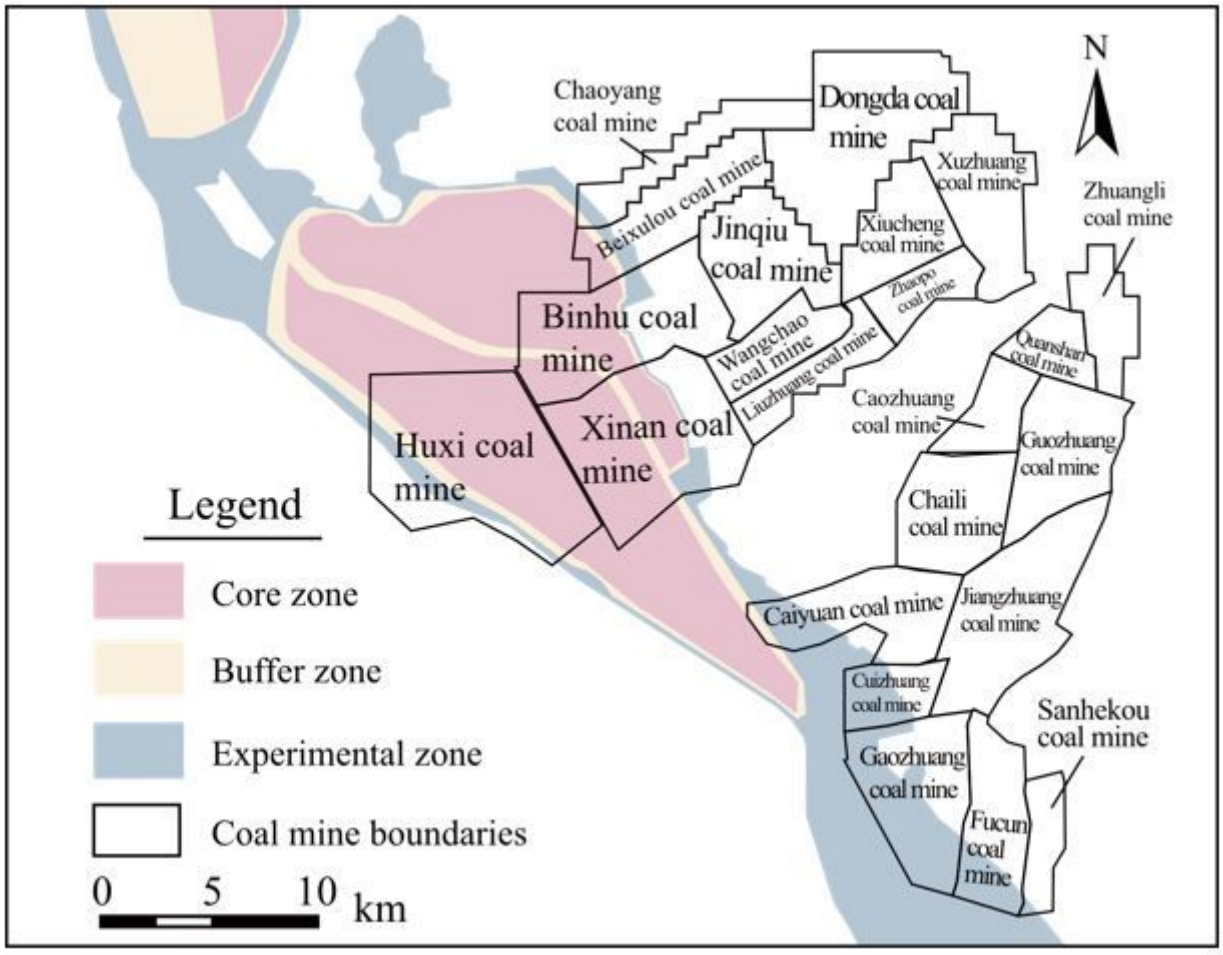

Figure 7

Distribution of mines around the upstream Nansi lake Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

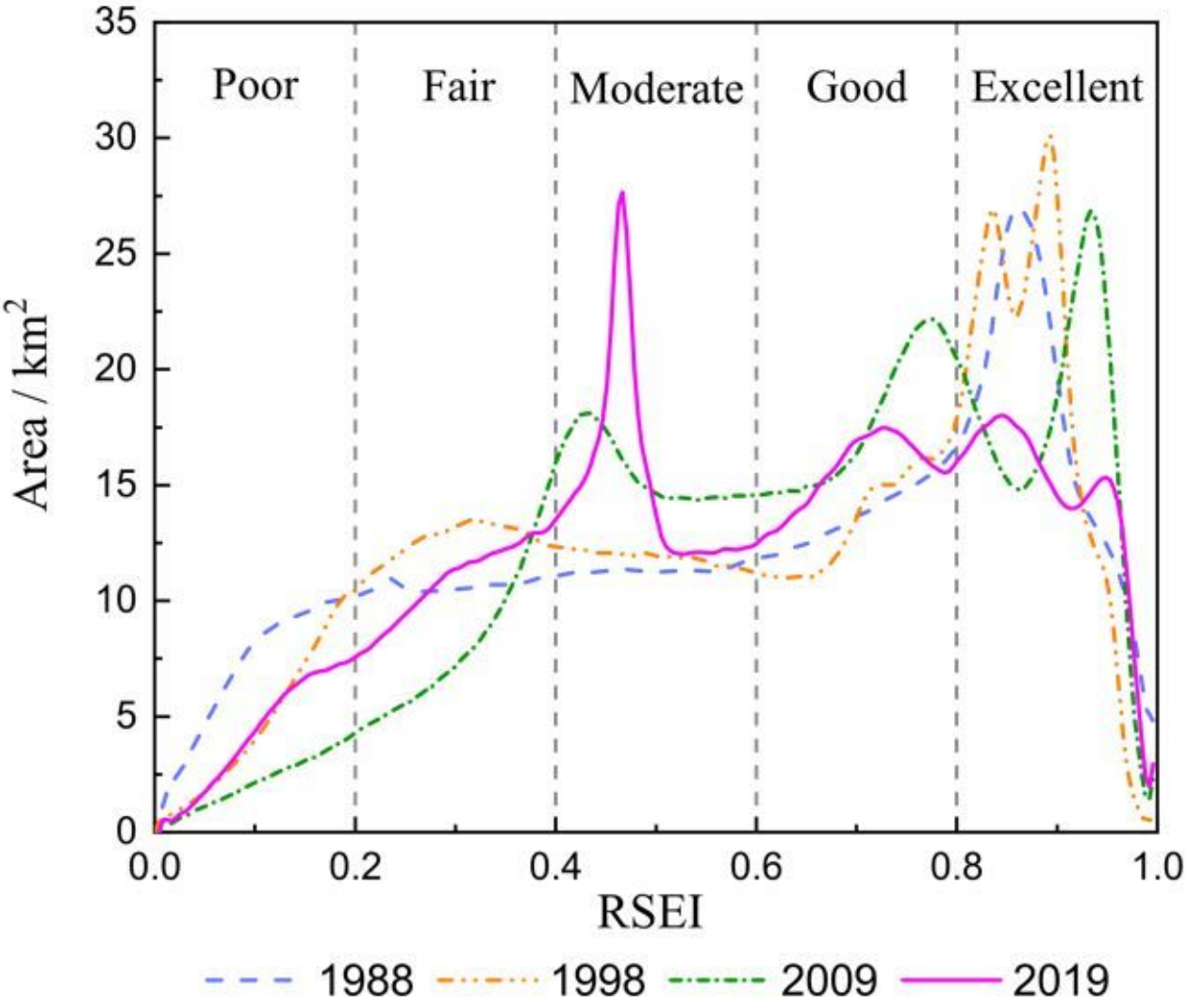

Figure 8

RSEI variation of the upstream Nansi lake