

RS and GIS based LULC change and water quality monitoring

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Abstract. Suzhou is one of the major cities in Yangtze River Delta, China. In recent years, severe urbanization has led to serious human-land conflicts between economic development and ecological environment and arable land occupation in Suzhou. Based on GIS and RS technology, this research investigates the composition and changes of the land structure of the LULC in Suzhou at the spatial and temporal scales between 1991 and 2021, and NDTI water quality measures are used to keep track of the turbidity of the water in Taihu Lake and the watersheds surrounding. The results show that the expansion of urban area in the LULC of Suzhou has been mainly at the expense of the reduction of agricultural land, while the urbanization process has slowed down and the ecological environment has been restored to some extent in the last decade due to the government's attention. This study analyzes the changes in LULC in Suzhou over a long-time span and provides decision support for the government's future rational use of land resources and urban planning and management, as well as solutions for maintaining sustainable urban development and ecological balance.

Keywords: LULC, Urbanization, Ecological environment, Sustainable development.

1. Introduction

Currently, with the world's population growing rapidly and 50% of the global inhabitants choose to settle in the urban [1], hasty urban expansion and rapid financial advancements bring new challenges to global climate change, ecosystem balance, agricultural maintenance and human-land relationship coordination [2, 3], urbanization and land use have emerged as key areas for the investigation of human impact on the environment [4]. Such population growth has made urbanization the global trend, which makes the urban structure and human-land ratio in great pressure [5], and the rapid and intensive encroachment of large land resources by build-up, with their destructive spatial expansion patterns, bringing a series of irreversible effects on the ecological system and sustainable socio-economic development [6, 7]. Land is a basic element and an important component of the earth. Due to the current severe situation of land resource shortage, governments in recent years have paid more attention to land resource information and the efficient use of socioeconomic resources and natural resources it contains [8, 9] as well as scientific planning and management under rapid land use changes [10], and have used as an indicative basis and determinant for regional ecological assessments and urban economic development plans [11].

Land use structure, Land use and Land cover (LULC) research integrate the influence of vegetation, water environment, soil and other factors on land use, focusing on the evolution of land use and analyzing how it affects local ecology in the context of the current rapid industrial and urbanization [12,13]. It has become an important signal for quantifying ecological change and natural resource management in both human and natural dimensions [14], and is widely used in various fields such as value of ecosystem services, human-land relationship coordination, agricultural production, natural disaster prevention and control [15], etc. Many studies have used LULC as an important quantitative research tool to investigate the rational allocation of natural resources and ecological conservation under land structure change [16], and to support decision-making on urban land use patterns and urban expansion planning [17].LULC is able to investigate how humans use natural resources and alter ecosystem structure and function, and plays an indispensable role in promoting land conservation and ecological construction and optimizing land use and spatial layout.

The development of remote sensing and GIS technology has provided LULC with high spatial and temporal resolution data and effective spatial and temporal analysis tools [18]. Through spatial

analysis methods such as supervised classification of land types, correlation analysis and time series [19], LULC and water quality changes in water bodies can be monitored dynamically in a digital and quantitative manner [20].

Suzhou is situated in the Yangtze River Delta's central section. Especially since the 21st century, after the reform and opening up, its social and economic development has been rapid due to the radiation influence of the mega-city Shanghai, and its urbanization process has continued [21]. The wetlands in the Taihu Lake area of Suzhou have been exploited on a large scale and transformed into land for construction and agriculture, and the contradiction between availability and demand for land resources and the contradiction between the occupation of arable land and its replenishment needs to be resolved [22]. Most of the current LULC studies in the Suzhou Taihu Lake basin span long time horizons [23], and are limited by primal GIS and RS technologies, and lack macroscopic analyzes of the effects of human activity on the local wetland environment and water quality based on macro-integrated LULC changes in the temporal dimension.

This study therefore aims to conduct a study on LULC and water environment quality monitoring at the Suzhou city level from 1991-2021 using scientific analysis methods such as GIS and RS in an era of continuous growth in industrialisation and urbanization levels. The study is important for meeting the new demand for land for urban construction and development in Suzhou, and for ensuring the ecological environment while developing and using land resources in a scientific and rational manner, and the findings can serve as a solid scientific foundation for Suzhou's land use planning, ecological environmental conservation, and sustainable development.

2. Materials

2.1. Study Area

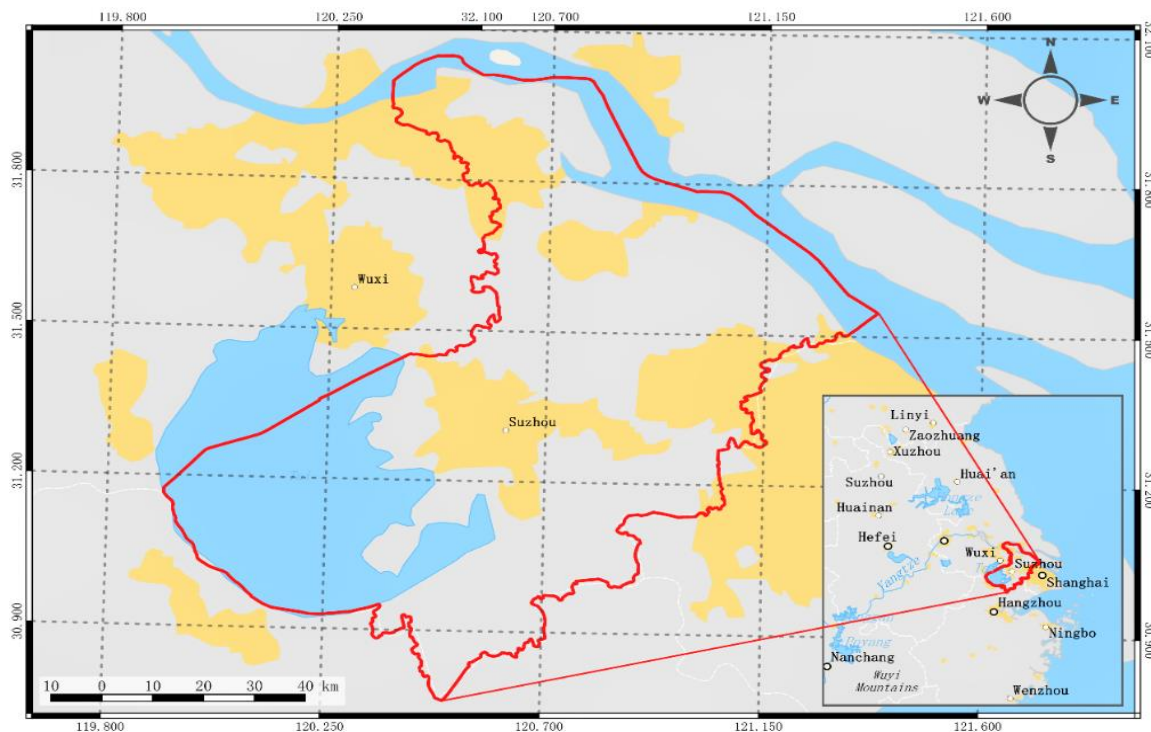


Figure 1. Study Area

According to figure 1, Suzhou is situated between 30°45' and 32°02' N latitude and 119°55' and 121°23' E longitude, in the center of the Yangtze River Delta and to the southeast of Jiangsu Province. It has a gentle topography, well-developed water system and a dense river network, and a topographic landscape of wetlands, low-lying lakeshore and hills, mainly developed by the Taihu Lake system. Suzhou is located in a prime location, with Shanghai, the mega-city adjacent to the east, as its core,

and its combination with the surrounding satellite cities such as Wuxi to form a world-class economic development city cluster, under its radiation-driven influence, the rapid development of township enterprises, the level of industrialisation is increasing. Suzhou has become a region in China with a high population density, a high level of economic technology and a significant urbanization trend. Especially since the 19th century, the proportion of construction land in Suzhou has grown rapidly, with large-scale urban expansion and development and industrial park construction leading to the disappearance of a large amount of wetlands and vegetation cover in the area around Taihu Lake, causing significant changes in land use structure, while industrial effluent discharge has also caused serious environmental problems in terms of pollution of surface water bodies such as lakes and rivers.

This study classifies the land use structure of Suzhou into four major categories: water bodies, vegetation cover, agriculture and build-up, to study LULC changes in Suzhou in the temporal dimension, to monitor the water quality pollution and environmental damage caused by its increasing industrialization level to marsh region surrounding Taihu Lake, as well as the middle and lower portions of the Yangtze River basin, and to propose reference solutions for alleviating the contradiction of human-land relationship and planning land use layout.

2.2. Data resource

Landsat remote sensing satellite data is utilized for a variety of purposes, including aiding in the management of forests and agriculture, monitoring the use of water resources, and assessing the Earth's environment, as well as playing an important role in land use classification studies.

In this study, four phases of 30m resolution Landsat5 and Landsat8 remote sensing satellite imagery from 1991, 2001, 2011 and 2021 were used to obtain the LULC data of Suzhou City at 10-year intervals between 1991 and 2021 after data pre-processing and land classification, based on the vertical development in time, supplemented by the LULC data released by ESRI. Geospatial Data Cloud (<http://www.gscloud.cn/#page5>) and USGS (<https://earthexplorer.usgs.gov/>) provided Landsat remote satellite data, While ESRI (<https://livingatlas.arcgis.com/landcover/>) provided the secondary LULC data for 2021.

3. Methods

3.1. Satellite images pre-processing

Remote sensing information acquisition is achieved through the reception of electromagnetic wave radiation reflected or emitted from targets by a sensor. Multispectral remote sensing data combines the image features of a ground target with spectral features, enabling accurate quantification of feature information and classification of the feature based on radiation values [24]. In the study of LULC variability over long time spans, the limitations of satellite operation time and advances in sensor development inevitably require the comparison of images taken with various sensors at different times. As a result, the radiometric calibration operation is performed on the acquired images to convert the brightness grey scale values of the images into absolute radiometric brightness in order to enable comparative analysis and classification of remote sensing images under different acquisition conditions. At the same time, the influence of the atmosphere, clouds and fog, etc. cause errors in the acquisition of the reflected value of the feature due to atmospheric water vapour, carbon dioxide and other substances in the atmosphere during the transmission of radiation from the feature target back to the sensor. To address the influence of atmospheric molecules and aerosols on the radiation values, the errors between the spectral information of the feature recorded in the image and the real information are corrected by atmospheric correction to restore the real spectral characteristics [25,26].

Radiometric calibration and atmospheric correction were performed to eliminate measurement errors and atmospheric effects in the radiometric values in the images, ensuring the accuracy and comparability of the classification results. Further image mosaicking and cropping operations were carried out on the corrected images using the Suzhou administrative area shapefile file as the boundary to obtain complete image for the research area.

3.2. LULC classification

LULC is a major application of remote sensing technology by identifying features, classifying attributes and extracting land use features from multispectral remote sensing image for the purpose of classification. The land in Suzhou is divided into five groups: water, forest, grassland, agriculture and construction land according to the Chinese land use status classification standard, using the maximum likelihood supervised classification approach in this study, combining waveband synthesis and image enhancement to emphasize the information of features to be classified and improve the accuracy of visual interpretation to obtain high accuracy classification results.

The maximum likelihood supervised classification method, which is simple to operate and incorporates Bayesian theory and prior knowledge, not only has high classification accuracy in LULC research [27,28], but also has the advantage of high computational efficiency [29]. In the classification process, the remote sensing image data are composited in true colour and false colour bands and combined with histograms to achieve image enhancement, which increases the image information and enhances image interpretation and recognition. The final study checked the accuracy and reliability of the classification by kappa statistics and confusing matrix.

Based on the LULC classification results, the study calculated the LULC changes in each decade from 1991 to 2021, and calculated the area changes and type transformation of each LULC category, especially highlighting the urban area expansion and urbanization rate. The formula to calculate the Urban growth rate is given as below:

$$\text{Urban growth rate} = \frac{\text{UrbanArea2} - \text{UrbanArea1}}{\text{UrbanArea1}} * 100\% \quad (1)$$

Where, UrbanArea1 is the urban area in the first year and UrbanArea2 is that in second year.

3.3. Water quality supervise

The composition and turbidity of water determine the optical properties of water, and The turbidity can be used to implement the following the water quality, so that the data base of remote sensing satellite images can be used to construct a correspondence between water quality parameters and the spectral characteristics of water [30]. In this study namely turbidity was selected to analyze and evaluate the changes of water quality in Taihu Lake in each year.

Calculating the Normalized Difference Turbidity Index (NDTI) allowed for the interpretation of the water turbidity of the Taihu Lake wetland , which was proposed by Lucas and Molenaar [30]. The following is the formula for the NDTI extraction:

$$\text{NDTI} = \frac{R - G}{R + G} \quad (2)$$

Where, R is red band (B3 in Landsat5, B4 in Landsat8) and G is Green band (B2 in Landsat5, B3 in Landsat8).

4. Results and Discussion

4.1. LULC Classification Approach

Applying GIS and RS technology, the Landsat multispectral remote sensing images of every 10-year interval between 1991 and 2021 were categorized using the supervised maximum likelihood classification approach to produce the LULC maps of Suzhou City in 1991, 2001, 2011 and 2021 (Figure1 to figure4), and further calculate the area of the various LULC categories and the proportion of the total area for each year to analyze the composition structure of LULC in Suzhou City under different years.

From 1991 to 2021, agricultural land ranked first in the LULC with a total area of 4648.09 KM² (53.52%), 4824.71 KM² (55.66%), 4278.56 KM² (49.36%) and 3734.88 KM²(43.09%) respectively.

In 1991, the area covered by vegetation, including woodland and grassland, was 7770.24 KM² or 8.87% of the total area and the built-up area was 594.225 KM² or 6.84% of the total area. In 1991, the urban area was only 6.84% of the total area of Suzhou, but in 2021 it has expanded to 18.64% of the total area, tripling in 40 years. This has been accompanied by a sharp reduction in agriculture (from 53.52% to 43.09%) and fluctuations in the area covered by vegetation. The details of Suzhou LULC from 1991 to 2021 are shown in table1.

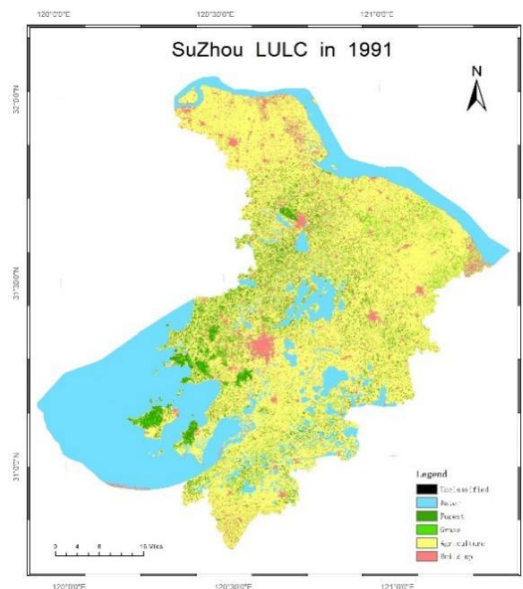


Figure 2. SuZhou LULC in 1991

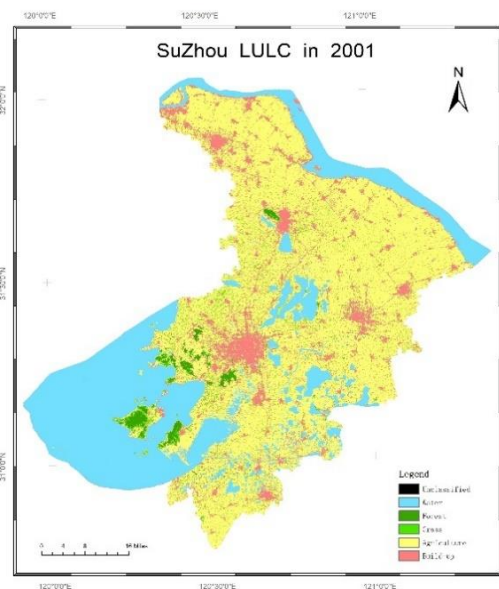


Figure 3. SuZhou LULC in 2001

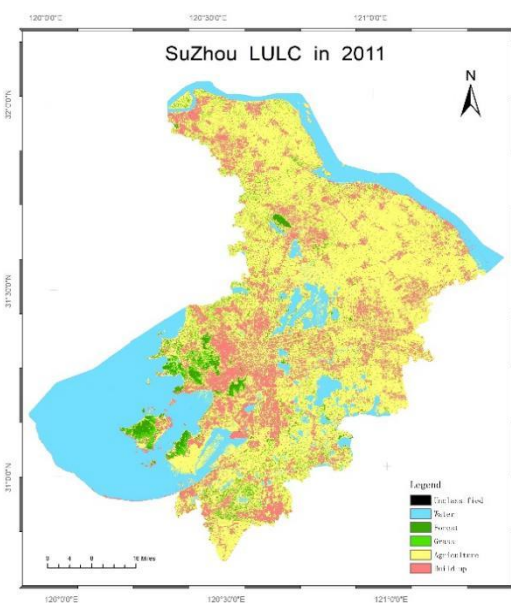


Figure 4. Suzhou LULC in 2011

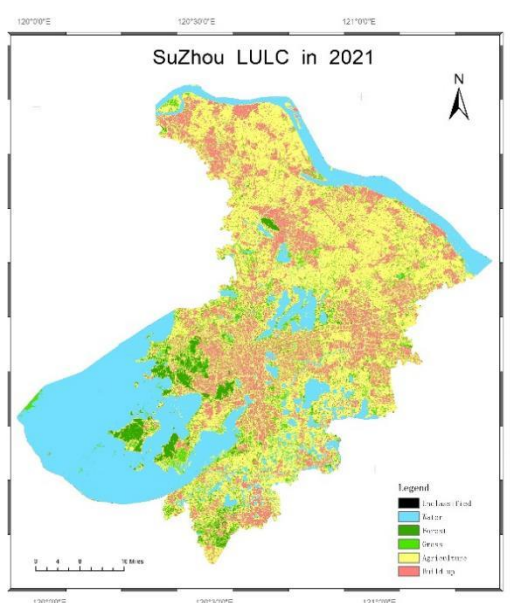


Figure 5. SuZhou LULC in 2021

Table 1. Statistic of SuZhou LULC in 1991, 2001, 2011, 2021

Year	1991		2001		2011		2021	
Statistic	Area /KM ²	Percent /%	Area /KM ²	Percent /%	Area /KM ²	Percent /%	Area /KM ²	Percent /%
LULC								
Water	2671.48	30.76	2553.17	29.45	2350.73	27.12	2521.08	29.08
Forest	577.41	6.65	125.44	1.45	190.10	2.19	271.48	3.13
Grass	192.83	2.22	201.33	2.32	304.37	3.51	525.55	6.06
Agriculture	4648.08	53.52	4824.70	55.66	4278.55	49.36	3734.88	43.09
Build-up	594.22	6.84	963.90	11.12	1544.79	17.82	1615.55	18.64

4.2. Accuracy Assessment

The classification accuracy of the LULC directly affects the detection of its changes. The research uses confusion matrices and Kappa coefficients to evaluate the accuracy and reference value of each classification result. Where the row data of the error matrix represents the actual site classification while the column data represents the classification results generated by the maximum likelihood classification method, the table2 depicts the details of the overall accuracy and the accuracy of each category. Overall LULC classification accuracy for the research region is 88.97%, 88.19%, 85.90%, and 88.36% for the years 1991, 2001, 2011, and 2021, respectively, all with a high level of confidence. The accuracy of Bulid-up is 90.27%, 86.41%, 84.32% and 81.49% respectively. As fro that, it is valid and credible to use these classified results for urban expansion studies.

Table 2. Overall Accuracy and Kappa Coefficient of classification

	1991	2001	2011	2021
Overall Accuracy	88.97%	88.19%	85.90%	88.36%
Kappa Coefficient	0.7585	0.8185	0.793	0.8256

4.3. Changes in LULC

The spatial and temporal changes in LULC are important indicators for both land resource planning and urban development management. The study examines the area of various land use categories and the percentage changes throughout the three time periods 1991–2001, 2001–2011, and 2011–2021, and highlights the growth rate of urban area. The LULC classification results clearly show that from 1991 to 2001, urban expansion had a significant impact on the city of Suzhou. The significant impact of LULC is evident in the fact that the trend of LULC change in the three time periods is more or less the same, with the area of vegetation cover and agricultural land decreasing while the area of building land increases year by year. Between 1991-2001 and 2001-2011, the growth rate of built-up land was extremely high, rapidly increasing from 6.84% to 17.82% of the total area at an average rate of 6% each year, with the area of built-up land in 2011 being 3.5 times larger than in 1991, but its growth rate declined significantly between 2011 and 2021, rising by just under 0.5% per year, according to the table3. It shows that the government is concerned about the impact of over-urbanization and has taken effective measures to mitigate it.

Table 3. LULC Change (1991-2001, 2001-2011, 2011-2021)

	1991-2001		2001-2011		2011-2021	
	Area/KM ²	Rate/%	Area/ KM2	Rate/%	Area/ KM2	Rate/%
Water	-118.3104	-4.43%	-202.4397	-7.93%	170.352	7.25%
Forest	-451.9674	-78.27%	64.6623	51.55%	81.3834	42.81%
Grass	8.5005	4.41%	103.0446	51.18%	221.1777	72.67%
Agriculture	176.6223	3.80%	-546.1533	-11.32%	-543.6711	-12.71%
Build-up	369.6831	62.21%	580.8861	60.26%	70.758	4.58%

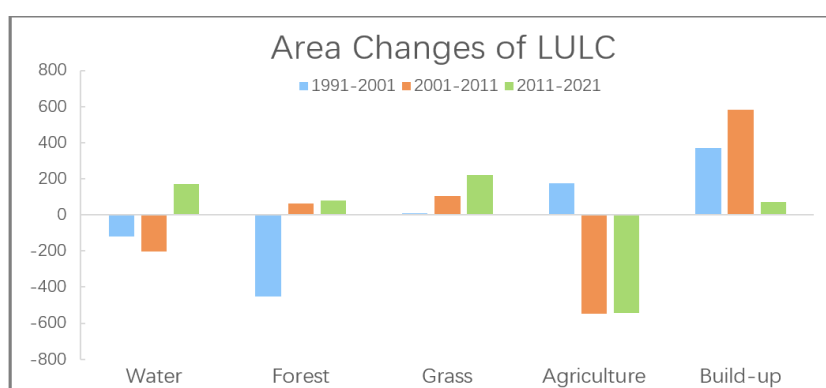


Figure 6. Area Changes of LULC

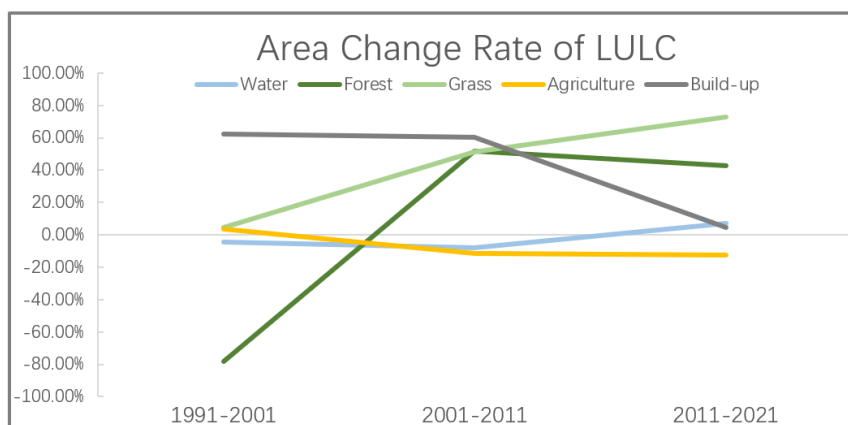


Figure 7. Area Change Rate of LULC

The opposite trend to the change in urban land area is that of agricultural land, which showed a general downward trend between 1991 and 2021. Although there was a small increase in agricultural land between 1991 and 2001, it eventually fell from 53.52% to 43.09% of the total surface. Although the area covered by vegetation continued to decrease between 1991 and 2011, and the area covered by forest decreased sharply, the area covered by grassland has been increasing slowly, probably related to the government's gradual attention to ecological protection and the construction of the lakeside zone by returning farmland to grass. This demonstrates how human activity-induced urbanization has resulted in a loss of agriculture and vegetation, posing a serious threat to the balance of human-land relations and the preservation of the ecological environment.

According to the LULC change statistics, a significant increase in urban area has been accompanied by a decrease in agricultural area. The increase in the area of building land has slowed down in the last 10 years, indicating that the government's control of building land has been effective. On the other hand, the decrease in arable land and the decline in water quality have increased the contradiction in food supply in Suzhou. The restoration of forest and grassland vegetation cover has enhanced the ecological services and suitability of Suzhou, and has somewhat reduced the city's vulnerability to air pollution and loss of biodiversity, although deteriorating water quality still poses a major challenge to the water environment.

4.4. Water Quality Supervise

Fourteen sample points were randomly selected within Taihu Lake, its surrounding ponds and the Yangtze River to obtain information on water quality parameters for every 10 years from 1991 to 2021, which were used as the basis for water quality monitoring. Points 1-7 were selected within the lake area of Taihu and Yangcheng Lake, points 8-10 were selected within the surrounding watershed of Taihu Lake, and points 11-14 were selected at the Yangtze River flowing through Suzhou City. Points 1-7 were selected within the lake area of Taihu and Yangcheng Lake, points 8-10 were selected within the surrounding watershed of Taihu Lake, and points 11-14 were selected at the Yangtze River flowing through Suzhou City.

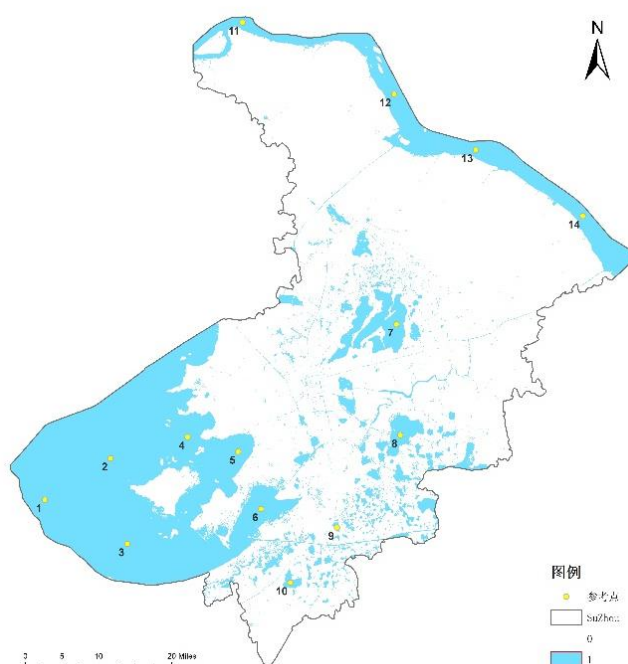


Figure 8. Spatial distribution of the fourteen sampling points

Table 4. NDTI value of sampling points

Point		NDTI1991	NDTI2001	NDTI2011	NDTI2021
1-7	MIN	-0.27092	-0.23124	-0.180345	-0.06763
	MAX	-0.21955	-0.12726	-0.10261	-0.0248
	AVG	-0.24135	-0.1567	-0.138054429	-0.04817
8-10	MIN	-0.24462	-0.20774	-0.166902	-0.05868
	MAX	-0.19653	-0.19204	-0.154064	-0.04252
	AVG	-0.21825	-0.19787	-0.158815333	-0.05043
11-14	MIN	-0.05826	-0.16384	-0.151438	-0.02975
	MAX	-0.03117	-0.08916	-0.0912949	-0.01759
	AVG	-0.04627	-0.12488	-0.127022975	-0.02223

The NDTI values for each point were calculated by waveband and the NDTI values within the different waters were counted, which are shown in table4. It can be seen that the water quality of Taihu Lake has increased in turbidity during the urbanization process, which is inextricably linked to the construction of a large number of factories around Taihu Lake. The ponds in its surrounding watershed have also seen an increase in turbidity due to human activities, with just a tiny area of the watershed distant from the city being less impacted.

5. Conclusion

This study uses GIS and RS technology to explore the changes of LULC in Suzhou city between 1991 and 2021, and to quantify the significant effects of human activity on the environment by monitoring the area changes of vegetation cover and agricultural land, as well as water quality in the Taihu Lake basin. The LULC classification results clearly show the structural changes of LULC in Suzhou city from 1991 to 2021 and the transformation trends of various types of LULC. The outcomes clearly illustrate the structural alterations of LULC in Suzhou from 1991 to 2021 and the transformation trends of various LULC types. This study also further demonstrates that GIS and RS technologies can reproduce LULC changes in the study area at spatial and temporal scales and visualise the area changes of various types of land cover, which can provide decision support for

regional ecological effective management and sustainable urban development. This project monitors the impact of LULC changes on the ecological environment and, together with the findings, facilitates the government to develop adaptive and mitigating interventions for urban development and environmental protection.

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