frontiers | Frontiers in Ecology and Evolution

ORIGINAL RESEARCH
published: 09 June 2022
doi: 10.3389/fevo.2022.918756

Quality Assessment of Ecological Environment Based on Google Earth Engine: A Case Study of the Zhoushan Islands

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Specialty section:
This article was submitted to Environmental Informatics and Remote Sensing, a section of the journal Frontiers in Ecology and Evolution

Received: *13 April 2022*
Accepted: *20 May 2022*
Published: *09 June 2022*

Citation:
Liu Z, Wang L and Li B (2022) Quality Assessment of Ecological Environment Based on Google Earth Engine: A Case Study of the Zhoushan Islands. Front. Ecol. Evol. 10:918756. doi: 10.3389/fevo.2022.918756

With the development of society, the impact of human activities on the ecological environment is becoming increasingly intense, so the dynamic monitoring of the status of the ecological environment is of great significance to the management and protection of urban ecology. As an objective and rapid ecological quality monitoring and evaluation technique, the remote sensing based ecological index (RSEI) has been widely used in the field of ecological research. Free available Landsat series data has the character of a long time series and high spatial resolution provides the possibility to conduct large-scale and long-term monitoring of ecological environment quality. Compared with traditional methods, the Google Earth Engine (GEE) platform can save a lot of time and energy in the data acquisition and preprocessing steps. To monitor the quality of the ecological environment in Zhoushan from 2000 to 2020, the GEE platform was used for cloud computing to obtain the RSEI, which can reflect the quality of the ecological environment. The results show that (1) from 2000 to 2020, the average RSEI value in Zhoushan Islands decreased from 0.748 to 0.681, indicating that the overall ecological environment exhibited a degradation trend. (2) From 2000 to 2020, the change in the area of each ecological environment level indicates that the quality of the ecological environment in Zhoushan Islands exhibited a degradation trend. The proportion of the area with an excellent eco-environment grade decreased by 13.54%, and the proportion of the area with poor and fair eco-environment grades increased by 3.43%.

Keywords: ecological environmental quality, RSEI, Google Earth Engine, Zhoushan Islands, cloud computing

INTRODUCTION

The environment is not only a basic condition for human existence and development but also an important cornerstone of sustainable social and economic development (Chen et al., 2020a,b; Jia H. et al., 2021; Nourani et al., 2021). Under global climate change and the intensification of human activites, many ecological problems have arisen, which have a significant impact on the ecosystems on which human beings depend for survival, resulting in the continuous decline of the restoration ability of the ecosystem (Pekel et al., 2016; Hussain and Khan, 2020; Alqadhi et al., 2021;

Chen et al., 2021a,b). Therefore, developing a method for the dynamic monitoring and evaluation of the quality of the ecological environment has become an important issue in ecological research.

For the past few years, scholars have been exploring quantitative methods of evaluating the regional environment. Thus far, promulgated by China's Ministry of Environmental Protection, the eco-environment index (EI) (Chiabai et al., 2018), which is based on ecological environment evaluation specification, and the remote sensing based ecological index (RSEI) proposed by Xu et al. (2018) are the most widely used to evaluate the regional environment (Hossain and Hashim, 2019; Bonney and He, 2021; Boori et al., 2021; Fu et al., 2021; Jia M. et al., 2021). The RSEI model has the advantages of easy parameter acquisition and a wide evaluation range, and it makes up for the index acquisition and analysis deficiencies of the EI so it is widely used in the evaluation of the quality of the ecological environment (Berberoglu and Akin, 2009; Chiabai et al., 2018; Xu et al., 2018; Eveleth et al., 2021; Firozjaei et al., 2021a,b). However, when applied to a large area, complex data processing and index calculation become a problem with the RSEI that cannot be ignored (Wen et al., 2019; Duan et al., 2021; Sun et al., 2021).

With the development of remote sensing technology, it is widely used in land use and cover change, forestry resource survey, and ecological environment monitoring (Yang et al., 2018; Chen et al., 2022). The Landsat series data meet the requirements of ecological environment quality monitoring due to its long time series and high spatial resolution (Yang et al., 2022). In recent years, the long time series, large spatial scale, fast, and accurate calculation of remote sensing data impose higher requirements for software and hardware (Chen et al., 2020a,b; Xiong et al., 2021). However, the Google Earth Engine (GEE) platform is a special tool for the batch processing of satellite image data, and it can quickly process a large number of images (Yang et al., 2020; Fan et al., 2021; Firozjaei et al., 2021b; Jia H. et al., 2021; Nietupski et al., 2021). Compared with traditional methods, it can save a lot of time and energy in the data acquisition and preprocessing steps. Thanks to the powerful computing ability and cloud storage features of the GEE platform, environmental monitoring studies based on this platform have been continuously carried out in recent years (Fan et al., 2021; Jia H. et al., 2021; Jia M. et al., 2021; Murayama et al., 2021).

The Zhoushan Islands are a typical archipelago region in China. As the first prefecture-level city established in the form of several islands, the city of Zhoushan has a relatively special geographic location. As it is naturally formed land areas surrounded by seawater and that remain above the water surface at high tide. Islands are very vulnerable to extreme weather or natural disasters, and thus, more attention should be paid to the protection of their ecological environment (Gernez et al., 2021; He et al., 2021; Murayama et al., 2021). Due to the intensification of human activities in recent years, the development of these islands has become more intense. Therefore, the monitoring of the ecological environment in the Zhoushan Islands is particularly important. Using the GEE platform, Landsat Thematic Mapper/Operational Land Imager (TM/OLI) image data were acquired in this study, and the RSEI model was used to carry out ecological environmental quality monitoring in Zhoushan from 2000 to 2020. The results of this study provide a reference for the formulation of policies and measures related to ecological restoration and protection and play an important role in the sustainable development of the ecological environment in this region.

MATERIALS AND METHODS

Study Area

The Zhoushan Islands as shown in **Figure 1** is located along the coast of Zhejiang Province. As the gateway to the Yangtze River valley, the developed Yangtze River Delta region gives this region significant resource advantages (Chen et al., 2021a, 2022). The Zhoushan Islands is the first prefecture-level city established in the form of an archipelago in China (Chen et al., 2021c). It consists of 1,390 islands with an area of over 500 m^2 (Wang et al., 2021a,b).

Data Source

The Landsat data were obtained from the United States Geological Survey (USGS) and were integrated on the GEE platform with a spatial resolution of 30 m. In this study, the surface reflectance (SR) datasets obtained using the Landsat 5 TM sensors in 2000, 2005, and 2010 were used. The SR datasets of the Landsat 8 OLI/Thermal Infrared Sensor sensors obtained in 2015 and 2020 were selected using the GEE platform. The obtained images are all images synthesized from the median of summer images in each year and they have been preprocessed, including radiometric correction, atmospheric correction, and geometric precision correction. Then, the Landsat cloud mask algorithm (Xiong et al., 2021) was applied in the GEE platform to conduct cloud removal from the obtained data. The data used in this study are listed in **Table 1**.

Methods

Based on the calculation formula for each component of the Landsat image proposed by Xu et al. (2018), in this study, remote sensing monitoring of the quality of the ecological environment was carried out using the GEE platform (Zhao et al., 2017). First, the Landsat satellite remote sensing data were acquired using the GEE platform, and cloud removal was conducted. Second, the normalized difference vegetation index (NDVI), humidity component (Wet), the normalized difference building-up and soil index (NDBSI), and land surface temperature (LST) were inverted to obtain the greenness, humidity, dryness, and heat indexes, and the results were subjected to standardized processing (Xu et al., 2018). Third, we conducted principal component analysis (PCA) and obtained PC1, which was used for the construction of the RSEI. Finally, the ecological environmental quality of the study area was classified, and the characteristics of the changes in the ecological quality in Zhoushan over the past 20 years were analyzed.

(1) Cloud Mask Processing

In this study, Landsat_SR image data were selected with an interval of 5 years from 2000 to 2020 in the GEE. The cloud content of the Landsat_SR image in the GEE was marked in the

TABLE 1 | Description of data used by the study.

Time	Satellite	Landsat collection	Sensor	Spatial resolution
2000 2005 2010 2015	Landsat 5	Collection 1_Surface Reflectance	Thematic mapper	30 m
2020	Landsat 8	Collection 1_Surface Reflectance	Operational land imager	Multispectral: 30 m Panchromatic: 15 m

"CLOUD_COVER" field (Foga et al., 2017). This field was used to screen all images with cloud contents of less than 50% in the study area. The mask function established according to cloud shadow and cloud attribute fields contained in the quality evaluation band "pixel_qa" in the Landsat_SR dataset image removed the cloud-containing area in each image.

(2) Calculation and Normalization of the Component Index

Xu used four important indexes of the environment as evaluation indexes of the eco-environment to construct the RSEI, namely, the greenness, humidity, heat, and dryness (Xu et al., 2018). In remote sensing, they are defined as the vegetation index, soil index, moisture component, and land surface temperature, respectively.

$$RSEI = f\left(NDVI, Wet, LST, NDBSI\right), \tag{1}$$

where NDVI is the normalized difference vegetation index, Wet is the wet component of the tasseled cap transformation, LST is the land surface temperature, and NDBSI is the normalized difference built-up and soil index. f indicates that the Remote sensing based ecological index can be expressed as a function of these four indicators.

Because each indicator has a different unit and value range, the four indicators need to be normalized separately using the following equation:

$$NIi = (Ii - Imin)\big/(Imax - Imin), \tag{2}$$

where NI_i is the result of the normalization of the indicators, I_i is the ith pixel value; I_{min} is the minimum value, and I_{max} is the maximum value (Yi et al., 2018).

(3) Calculation of the Remote Sensing Based Ecological Index

The principal component transformation was used to construct the RSEI. The main information for the four indicators was mainly concentrated in the first principal component (PC1), which enables the RSEI to comprehensively reflect the information about the four indicators. PCA is a multi-dimensional data compression technique. This method rotates the coordinate axis vertically and concentrates the information about multiple variables into a few feature components through linear transformation (Yi et al., 2018; Turpie et al., 2021). This method can avoid the deviation of subjective factors during the weight assignment process, which makes the RSEI more objective and reliable.

To make a large value of PC1 represent good ecological conditions, the first principal component of the function of these four indicators can be further subtracted from 1 to obtain the initial ecological index $RSEI_0$, and the formula is as follows:

$$RSEI0 = 1 - PC1\left(f\left(NDVI, Wet, LST, NDBSI\right)\right). \tag{3}$$

where $RSEI_0$ is normalized to facilitate the measurement and comparison of the indicators as follows:

$$RSEIf = (RSEI0 - RSEI0\_\min)\big/(RSEI0\_\max - RSEI0\_\min). \tag{4}$$

The obtained $RSEI_f$ value is within the range of [0–1]. The closer RSEI is to 1, the better the quality of the eco-environment of the region (Xu et al., 2018; Sekovski et al., 2020).

RESULTS AND ANALYSIS

Results of Principal Component Analysis

The first to fourth principal component analysis index values can be expressed as PC1, PC2, PC3, and PC4, respectively, as shown in **Table 2**.

Table 2 shows the results of the principal component analysis from 2000 to 2020 in the study area. It can be seen from **Table 2** that (1) The contribution rates of the first principal component from 2000 to 2020 all exceeded 70%. The contribution rates of PC1 in 2000, 2005, 2010, 2015, and 2020 were 71.81, 75.88, 77.71, 72.74, and 82.68%, respectively. (2) Compared with the other components, the first principal component contained more than 70% of the characteristic information about each indicator. Therefore, it can integrate the information about each indicator better, representing the characteristics of the regional ecological environment,

TABLE 2 | The results of the principal component analysis.

Year	Index	PC1	PC2	PC3	PC4
2000	Eigenvalue	0.0703	0.0207	0.0061	0.0008
	Percent eigenvalue	71.81%	21.11%	6.23%	0.85%
2005	Eigenvalue	0.0783	0.0207	0.0035	0.0007
	Percent eigenvalue	75.88%	20.11%	3.37%	0.64%
2010	Eigenvalue	0.0627	0.0120	0.0059	0.0001
	Percent eigenvalue	77.71%	14.84%	7.31%	0.15%
2015	Eigenvalue	0.0706	0.0168	0.0093	0.0004
	Percent eigenvalue	72.74%	17.29%	9.56%	0.41%
2020	Eigenvalue	0.0854	0.0124	0.0053	0.0003
	Percent eigenvalue	82.68%	11.97%	5.10%	0.25%

and it can be used to establish the Remote sensing based ecological index.

Table 3 shows that the quality of the ecological environment in Zhoushan was generally good from 2000 to 2020, and the mean value of the Remote sensing based ecological index initially decreased and then slowly increased. The mean value of the Remote sensing based ecological index decreased from 0.748 in 2000 to 0.668 in 2010, and then, it remained

TABLE 3 | Mean values of normalized ecological environment factors in Zhoushan.

	2000		2005		2010		2015		2020	
	Mean	**Std**	**Mean**	**Std**	**Mean**	**Std**	**Mean**	**Std**	**Mean**	**Std**
Greenness	0.483	0.260	0.480	0.278	0.477	0.239	0.464	0.251	0.694	0.271
Wetness	0.629	0.117	0.697	0.095	0.897	0.030	0.674	0.066	0.529	0.055
Dryness	0.559	0.114	0.461	0122	0.408	0.121	0.449	0.135	0.452	0.140
Heat	0.560	0.089	0.516	0.080	0.545	0.107	0.376	0.130	0.444	0.116
RSEI	0.748	0.185	0.712	0.202	0.668	0.202	0.666	0.166	0.681	0.188

TABLE 4 | Statistics of ecological quality grade and area of Zhoushan.

RSEI	2000		2005		2010	
	Area (km^2)	**Scale (%)**	**Area (km^2)**	**Scale (%)**	**Area (km^2)**	**Scale (%)**
Poor [0–0.2]	10.20	0.81%	17.13	1.36%	19.39	1.54%
Fair [0.2–0.4]	85.01	6.75%	118.49	9.41%	172.91	13.73%
Moderate [0.4–0.6]	150.67	11.97%	192.16	15.26%	202.70	16.10%
Good [0.6–0.8]	354.58	28.16%	360.64	28.64%	425.65	33.81%
Excellent [0.8–1]	658.56	52.31%	570.60	45.32%	438.39	34.82%
RSEI	**2015**		**2020**			
	Area (km^2)	**Scale (%)**	**Area (km^2)**	**Scale (%)**		
Poor [0–0.2]	7.26	0.58%	4.48	0.35%		
Fair [0.2–0.4]	81.23	6.47%	136.35	10.64%		
Moderate [0.4–0.6]	339.13	27.00%	289.66	22.60%		
Good [0.6–0.8]	497.89	39.63%	354.22	27.64%		
Excellent [0.8v1]	330.71	26.33%	496.86	38.77%		

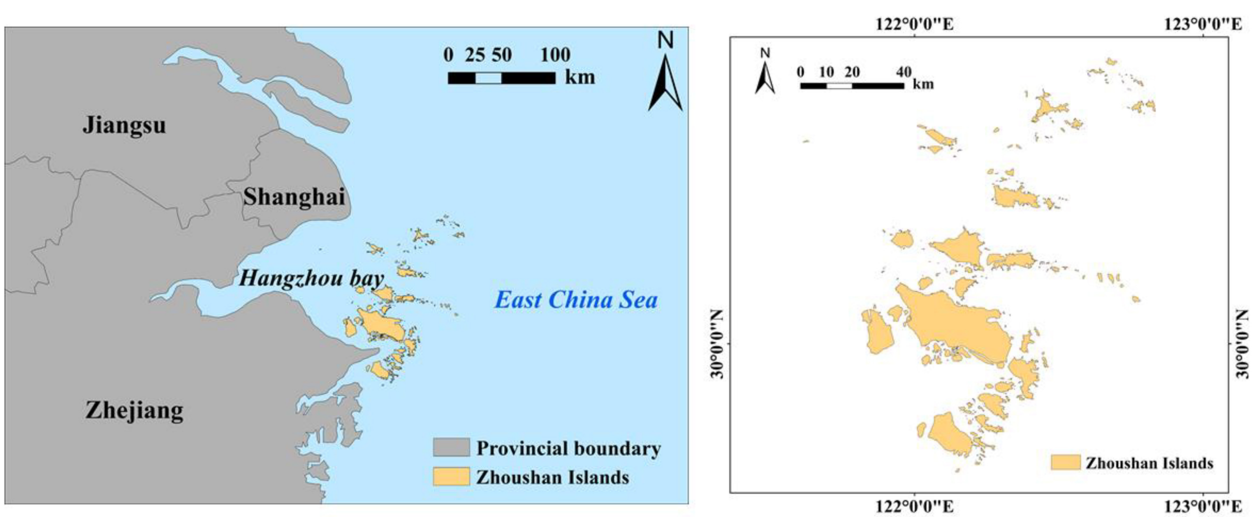

FIGURE 1 | Location of the study area.

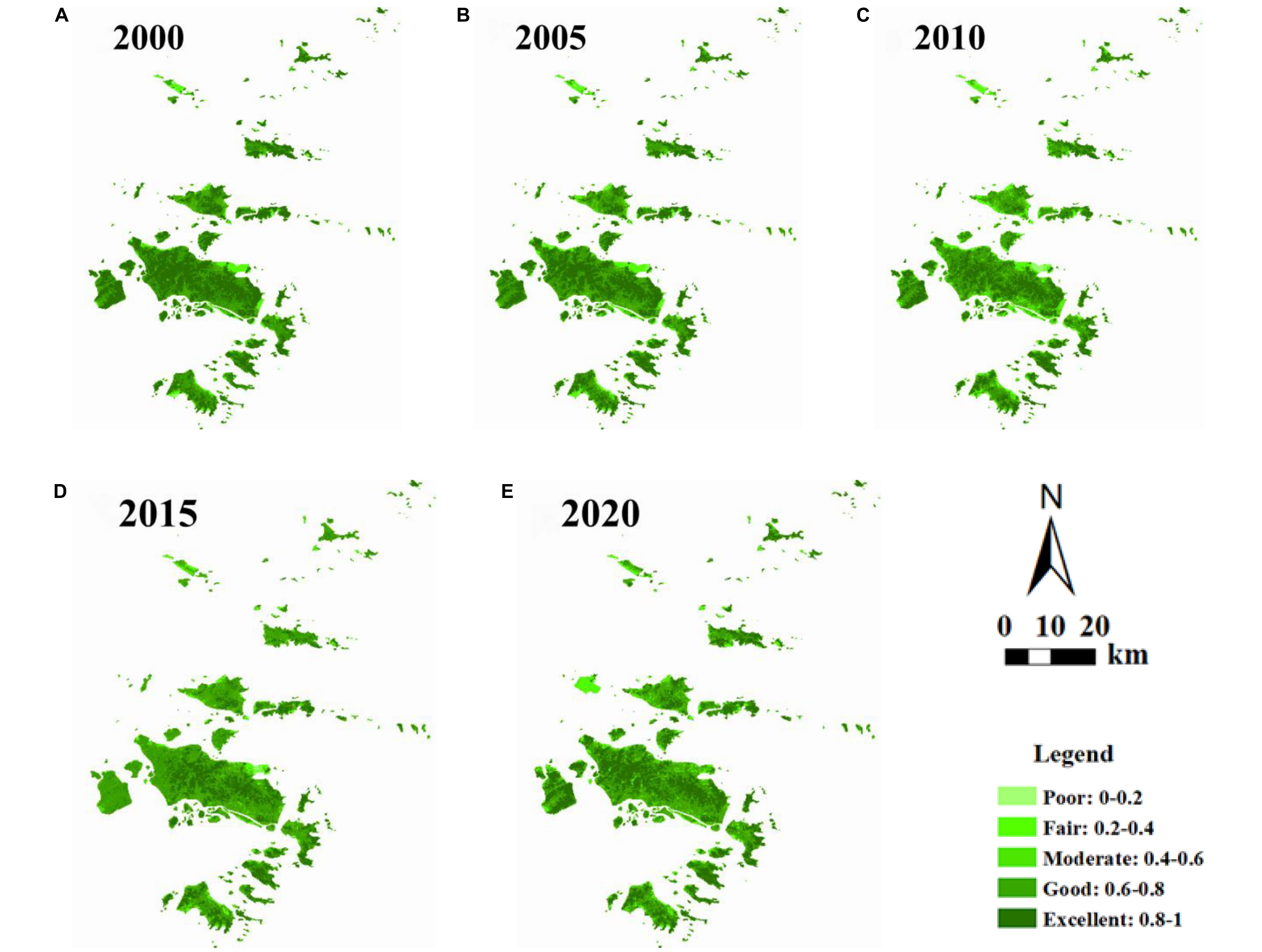

FIGURE 2 | Spatial distribution of RSEI in Zhoushan Islands during 2000–2020.

basically unchanged until 2015 (0.666). Finally, it increased to 0.681 in 2020. This indicates that the eco-environmental quality in Zhoushan exhibited a slowly increasing trend after decreasing. During the study period, the standard deviation of the Remote sensing based ecological index was low, indicating a high degree of data concentration and that the research results are reliable.

Analysis of Temporal Changes in the Quality of the Ecological Environment

To better analyze the quality of the ecological environment in Zhoushan, according to the Technical Specifications for the Assessment of the Ecological and Environmental Conditions issued in 2015 (HJ/T192-2006) (Firozjaei et al., 2021a), the ecological and environmental quality was divided into the following five grades with a 0.2 interval: poor [0–0.2], fair [0.2–0.4], moderate [0.4–0.6], good [0.6–0.8], and excellent [0.8–1]. The results are presented in **Table 4** and **Figure 2**.

Figure 2 and **Table 4** show the changes in the areas of the various eco-environmental grades in Zhoushan from 2000 to 2020. The results show that (1) from 2000 to 2020, the area with an excellent eco-environmental grade in Zhoushan decreased by 13.54%, and the area with poor and fair eco-environmental grades increased by 3.43%, so the overall quality of the eco-environment exhibited a degradation trend. (2) In 2000 and 2005, the quality of the eco-environment in Zhoushan remained basically stable, the overall quality of the eco-environment was mainly excellent, accounting for about 50% of the total area. In 2000 and 2005, the area with a good eco-environment grade accounted for 28.16 and 28.64%, respectively. The area with moderate eco-environmental quality increased from 11.97% in 2000 to 15.26% in 2005. In 2005, the area with poor and fair eco-environment grades accounted for 10.77%, an increase of 40.41 km^2 compared with 2000. (3) In 2010, the overall eco-environmental quality was predominantly excellent and good, accounting for 34.82 and 33.81% of the total area, respectively. Compared with 2005, the area with an excellent grade decreased by 132.21 km^2. In addition, the area with poor and fair eco-environment grades accounted for 15.27%, an increase of 56.68 km^2 compared with 2005. This shows that from 2005 to 2010, the eco-environment exhibited a degradation trend. (4) In 2015, the area with poor and fair eco-environment grades decreased by 8.22%, indicating a significant increase in the eco-environmental quality compared with 2010. However, the area with an excellent eco-environment grade decreased by 107.68 km^2 from 2010 to 2015. (5) In 2020, the eco-environmental quality was predominantly excellent. Compared with 2010 and 2015, the area with an excellent eco-environment grade was significantly higher in 2020, accounting for 38.77%, while the area with a poor eco-environmental grade was significantly smaller. This shows that there was a trend of improvement in the ecological environment from 2010 to 2020.

CONCLUSION

In this study, the RSEI for Zhoushan from 2000 to 2020 was analyzed using the GEE platform. These results provide a decision-making basis for the sustainable development of the ecological environment in Zhoushan. The main conclusions are as follows.

(1) The mean value of the RSEI in Zhoushan initially decreased and then slowly increased from 2000 to 2020. The mean value of the RSEI decreased from 0.748 in 2000 to 0.668 in 2010, then increased to 0.681 in 2020.
(2) It can be concluded that the overall ecological environment in the region exhibited a degradation trend during the study period. The area with an excellent eco-environment grade decreased by 13.54%, and the area with poor and fair eco-environment grades increased by 3.43% from 2000 to 2020.

However, this study also needs to be extended in the following aspects. (1) The temporal and spatial evolution of the RSEI in the key areas of the Zhoushan Islands greatly affected by human activities should be analyzed to better reveal the changes in the RSEI in Zhoushan. (2) In order to improve the monitoring model of the quality of the ecological environment in Zhoushan, other indexes reflecting the quality of the ecological environment can be selected to add to the analysis in the future.

DATA AVAILABILITY STATEMENT

The original contributions presented in this study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct, and intellectual contribution to the work, and approved it for publication.

FUNDING

This work was supported by the National Key Research and Development Program of China (No. 2018YFC1503204-04) and the National Natural Science Foundation of China (Grant No. 42171311), the Training Program of Excellent Master Thesis of Zhejiang Ocean University, and the Project of Beijing VMinFull Limited (VMF2021RS).

ACKNOWLEDGMENTS

We thank LetPub (www.letpub.com) for its linguistic assistance during the preparation of this manuscript.

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Conflict of Interest: BL was employed by Beijing VMinFull Limited.

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