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Multidimensional analysis of remote sensing monitoring data and quantitative assessment of ecological effects in marine ecological reserves

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ABSTRACT
Based on the wide application of satellite remote sensing in the field of ecology and environment, the study builds a remote sensing monitoring system for marine ecological reserve, processes the marine remote sensing data by using the technologies of GeoTools, NetCDF and GeoServer, builds a WebGIS system, and collects, transmits and integrates and processes the marine ecological data through the data collection module and the visualization query module. Selecting Laizhou Bay as the study area, the system of this paper was used to collect and process the ecological remote sensing data within the study area during the period of 2003-2022, and to carry out multidimensional analyses including the factors of sea surface temperature and photosynthetically active radiation, sea surface salinity and degree of eutrophication, and so on. A marine ecological health assessment index system was constructed to assess the ecological health of Laizhou Bay and explore its spatial and temporal distribution characteristics. During the period 2003-2022, sea surface temperature and photosynthetically active radiation (AWEI) in the Laizhou Bay region showed an overall increasing trend, and sea surface salinity showed a slight decreasing trend. The total area of mariculture and the total area of zizyphus culture were generally on the rise, and the eutrophication of the water body in Laizhou Bay was most serious in 2013, with the AWEI reaching the maximum value (1.00), which was mitigated after 2013, and the AWEI was reduced to 0 in 2022.The integrated health index (IHI) of the ecosystem of Laizhou Bay increased gradually in 2003, 2012 and 2022, and the health status changed to "healthy", and the area of healthy zone expanded to "healthy". In 2003, 2012 and 2022, the integrated health index (IHI) of the Laizhou Bay ecosystem gradually increased, the health status changed to "healthy", and the area of the healthy zone expanded by 54.54%.

Keywords: remote sensing monitoring, WebGIS, multidimensional analysis, marine ecology

1. Introduction

The oceans are the basis for human survival and development, and their rich natural resources and

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the ecosystem services they provide provide an important guarantee for human development. At present, along with the rapid economic and social development of coastal areas and the increase in population pressure, the demand for human activities for the exploitation and utilization of the oceans is becoming increasingly intense. This has directly or indirectly led to the reduction of natural shoreline year by year, the decline of marine ecological function, serious near-shore seawater pollution, the reduction of biodiversity, and the frequent occurrence of seawater intrusion, red tide and other disasters [1-3]. Facing the severe situation of tightening marine resource constraints, serious environmental pollution, and ecosystem degradation, it is necessary to establish the concept of ecological civilization of respecting nature, adapting to nature, and protecting nature, and take the road of sustainable development [4-5]. In this context, according to the technical principles of remote sensing and geographic information system, designing a set of remote sensing monitoring data assessment program for marine ecological reserve has a positive significance for controlling the natural attributes of the sea area as well as the threat of exploitation [6-7].

The monitoring of marine ecological environment requires appropriate spatial resolution and time sampling frequency, with the help of remote sensing monitoring data of marine ecological environment, we can understand the basic conditions of biochemical and physical properties of offshore water, which can provide help for the protection of marine biodiversity and marine ecological fragile zones, as well as the offshore aquaculture industry and fishery industry [8-10]. It can also characterize and detect the changes of coastal water quality, and provide support for the study of shoreline migration, coastal engineering and its impact on coastal ecosystems [11-13]. Using long time series remote sensing data, it is possible to monitor the inter-annual changes in marine ecosystems, to study the impact of environmental fluctuations on marine ecology under climate change, and to evaluate the impact of regional climate change perturbations on marine ecology [14-16]. To study the distribution characteristics and long-term change trends of marine ecosystems, these parameters cannot be monitored without the support of operational ocean water color remote sensing products and regular in situ accuracy tests.

In this paper, GeoTools, NetCDF and GeoServer are utilized to process the marine ecological reserve data from satellite remote sensing, and after geometric correction and resampling of the data, a WebGIS system is built. The data transmission network of the marine ecological monitoring system is integrated and processed, and the data transmission integration is realized through the data acquisition module and the visualization query module to build the remote sensing monitoring system of marine ecological reserves. Based on the marine ecological data in the system, Laizhou Bay is selected as the research object, and the sea surface temperature and photosynthetically active radiation, sea surface salinity and eutrophication degree of Laizhou Bay are analyzed multidimensionally during the period of 2003-2022. A marine ecological assessment system was constructed to assess the marine ecology of Laizhou Bay and explore its spatial and temporal characteristics.

2. Construction of a remote sensing monitoring system for marine ecological protected areas

2.1. Related technologies

2.1.1. Open Source GIS Development Tools – GeoTools. OGC (Open Geospatial Consortium) provides a standard specification for geographic information development, GeoTools is an excellent open source Java library developed following this specification, WebGIS applications, client-side GIS applications can be built using GeoTools [17]. By calling the method interfaces provided by GeoTools, you can achieve the data layer to the performance layer of GIS operations. geoTools modular organization is clear, loosely coupled feature-rich, scalable. The desktop GIS application uDig and the geographic information server Geoserver are developed using GeoTools as a tool.

GeoTools is divided into different components according to its functions, and each component is independent and interconnected with each other. developers can use only a certain part of the functions, or extend the new functions developed by themselves by inheriting the classes of the required components, or replace the initial values of the other formations with another method of the components, which can increase the flexibility of the programming. structure is shown in Figure 1.

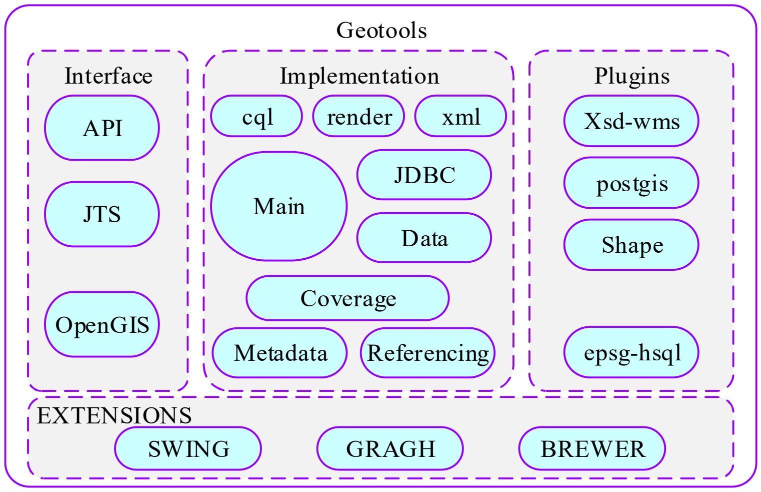


Fig.1. GeoTools function and structure

2.1.2. Raw Data Model-NetCDF. NetCDF (Network Common Data Format) is a customized data format, a standard for describing and encoding data that is array-oriented and suitable for network sharing, and supports the creation of, access to, and sharing of array-oriented scientific data. The format is an open standard.NetCDF Classic and the 64-bit offset format are international standards of OGC.

2.1.3. GeoServer REST API. GeoServer provides a REST interface for the backend to retrieve instances and modify configurations. Using the simple HTTP call of the REST interface, the backend can directly use the code to configure the geoserver without the need to use the Web management interface.

Open source GeoServer is powerful , supports multiple data sources , map configuration (SLD), layer Layer and layer group Group, a variety of OGC standard services , such as WFS, WMS, WCS and so on. However, when you need to manage GeoServer in an external program, such as calling geoserver in an external program to publish SHP, images (TIFF), spatial tables (POTGIS) into a map service, configure relevant styles for published layers, delete a layer, or Store or Workspace, The REST interface can fulfill this function.

2.2. Data processing methods

2.2.1. Geometric correction. The principle of geometric correction is to convert the image containing aberrations to the corresponding position of the specified projection map [18]. Geometric correction methods are optomechanical and numerical correction methods, the former is mostly used for geometric correction of images taken by static sensors, and the latter is mostly used for geometric correction of images taken by dynamic sensors. Numerical correction method in accordance with the corrective mathematical model, can be divided into parametric and non-parametric method. The parametric method is to simulate and solve the deformation rules of the image, or the position and attitude of the sensor in flight, to find out the conversion parameters, and then use these parameters to calculate all the pixels, which is often solved by polynomials or covariance equations. The non-parametric method is based on the geometrical changes in the control points, and then deduce the number of corrections for the other image points.

2.2.2. Resampling. Images produced from remotely sensed data need to pass through resampling techniques or other forms of validation processes that would otherwise reduce the reliability of the final product. They determine the cell values of the output raster after the geometric transformation operation has been performed. The exact method to be used depends on the input data and its use after performing the operation. It is not just one method of resampling, but there are multiple ways to recalculate the cell values. There are three common methods for resampling raster grids in GIS: nearest neighbor, bilinear interpolation, and cubic convolution.

Cubic convolution is often considered better than bilinear interpolation and does not suffer from severe pixelation of nearest neighbor interpolation. The time complexity of the cubic convolution method is higher because it requires more neighboring cells than the bilinear interpolation method. This method is suitable for resampling of aerial films and remote sensing images. Meanwhile, the cubic convolution method is favorable for noise reduction. For example, the cubic convolution interpolation technique is applied to radar images, which reduces the noise commonly found in radar.

2.3. System design

2.3.1. WebGIS construction. WebGIS is the web page geographic information system [19]. WebGIS has a three-layer structural system: the representation layer, the logical layer and the data layer, in which the logical layer consists of the GIS Server and the Web server, the GIS Server and the Web Server can be integrated or distributed in different servers. The representation layer is responsible for sending user requests to the logical layer and displaying the data or geographic information data returned by the logical layer. The representation layer may also have some spatial analysis capabilities, so that the load balance between the representation layer and the logical layer. web server is between the client and the GIS Server, responsible for the client and the GIS Server communication protocols and request response.

2.3.2. Dynamic website construction-JSP. JSP can create dynamic, interactive web server applications. JSP has the advantages of Servlet, but also can be embedded directly into the HTML, so that the development of the program has become faster and simpler.

A simple Web page can only use HTML to complete, but to make the page has the basic interactive capabilities of the need for style sheets (CSS) and the common realization of JavaScript. jQuery provides a series of page modification of a simple method, through the jQuery can be a direct page of HTML elements for the selection, manipulation, operation of the CSS, use of the AJAX front-end and back-end asynchronous communication and so on. Bootstrap is based on HTML, CSS and JavaScript, in the jQuery based on a set of beautiful, personalized style. Through the jQuery call and AJAX-related methods to send requests to the server side. The server side can access the database or execute SQL statements through JDBC (database connection driver), thus realizing the development of a complete JSP dynamic website. The structure of JSP is shown in Figure 2. The dynamic website development using JSP in WebGIS can access the geographic information database in real time and retrieve the required geographic data asynchronously through AJAX, and finally display the visualization results on the page, which is very convenient.

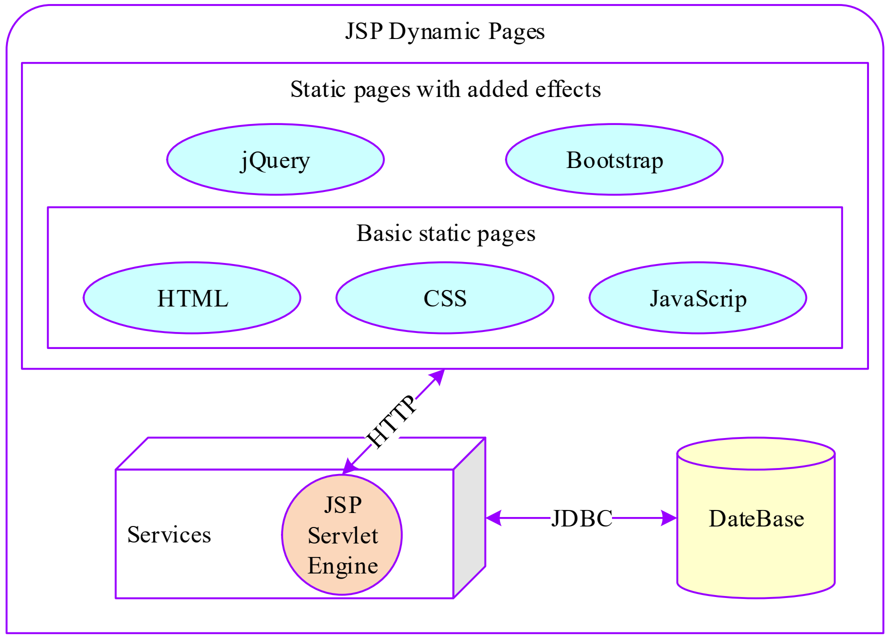


Fig. 2. JSP structure

2.4. Integration of marine ecological monitoring system data transmission

Because in the marine environment monitoring system data transmission network design for different monitoring project characteristics and real-time requirements and the amount of data designed to use different means of transmission, and by a variety of monitoring means composed of integrated monitoring system, it is necessary to establish a communication network console on different means of communication unified control, scheduling in order to be able to the whole system to operate in an orderly manner, the various monitoring sub-systems data collection also needs to be automated to complete and control management. The data collection of each monitoring sub-system also needs to be automated and controlled, so it is necessary to design and develop the data communication management and monitoring application software system, to carry out the system's data collection control and visualization and integration query, to realize the automatic data collection of various ecological environment monitoring systems, the functions of storage and monitoring of each system's operation status, so that the system managers can real-time monitoring of each system's monitoring data collection and storage and the system's operation status, and to diagnose system faults and automatically generate the system's operation status. system faults, automatically generate system operation logs, security control, etc., and real-time retrieval of received data.

2.4.1. Modules and functions. The monitoring data transmission integration can be divided into two parts: data acquisition module and visualization query module. Among them, the data acquisition module has:

(1) Underwater unmanned monitoring station data acquisition module.
(2) Ocean station hydrometeorological observation data acquisition module.
(3) Ecological buoy monitoring data acquisition module.
(4) Shipboard monitoring data acquisition module.
(5) Airborne remote sensing drone remote sensing monitoring data acquisition module.
(6) Satellite remote sensing data acquisition module.

From the perspective of functional realization, the data integration function module mainly includes:

(1) The data sending and receiving processing module completes the interpretation and execution of the data protocol and deposits the received data into the specified buffer.

(2) Data storage processing module will receive the data in a certain file format into the disk.

(3) The communication management module monitors the communication status, records the amount of communication data, and interfaces with other programs.

(4) The real-time data collected for on-site monitoring will be displayed and at the same time stored in the specified directory in the form of a file according to the site and time sequence, which will be provided to the information application system for calling and accessing by the users concerned.

2.4.2. Data flow. The main data of the data monitoring software can be categorized into the following seven types according to the source of the data: data from the shipborne rapid monitoring system, UAV remote sensing monitoring data, satellite remote sensing monitoring data, aerial remote sensing monitoring data, ecological buoy monitoring system, monitoring data from the underwater unmanned station monitoring system, and routine operational monitoring data. The data flow is shown in Figure 3.

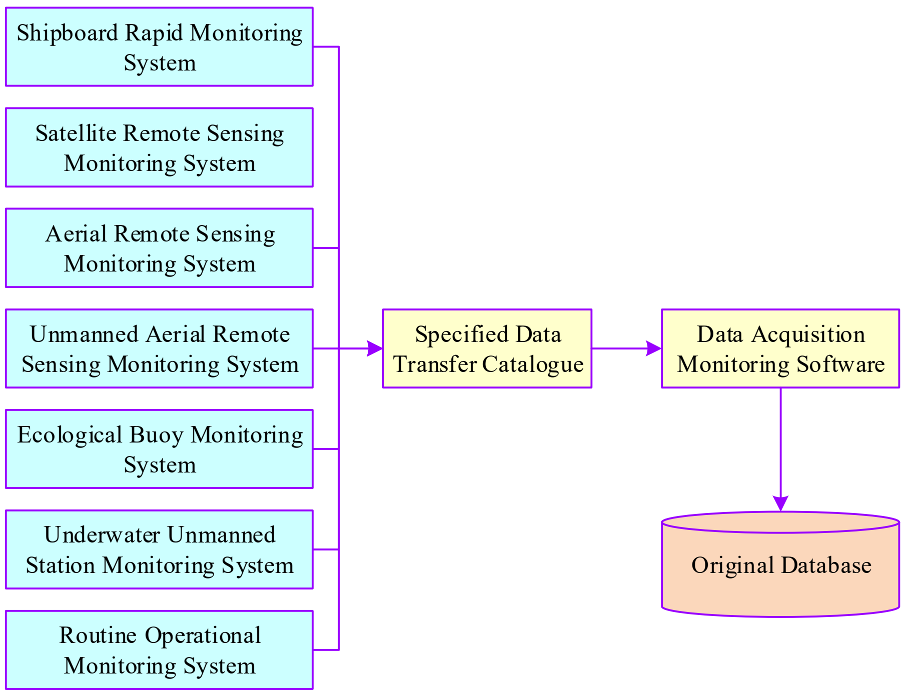


Fig. 3. Main data source and data process

2.4.3. Monitoring data collection. The system integrates a total of sub-systems unmanned automatic monitoring stations, ecological buoy systems, shipborne rapid monitoring systems, aerial remote sensing monitoring, drone remote sensing monitoring, satellite remote sensing monitoring, as well as conventional monitoring systems. The monitoring data transmitted need to be collected and processed, and standardized documents need to be formed, as required.

2.4.4. Monitoring data query and system operation monitoring. The system mainly carries out data acquisition control and visualization integration query, realizes the function of automatic data acquisition, storage and monitoring of the operation status of each system of various ecological environment monitoring systems, so that the system manager can monitor the monitoring data acquisition and storage of each system and the operation status of the system in real time, diagnose the system faults quickly, generate the operation log of the system automatically, safety control, etc., and retrieve the received data in real time. The system can also retrieve the received data in real time. The realization process of the data visualization query system is shown in Figure 4.

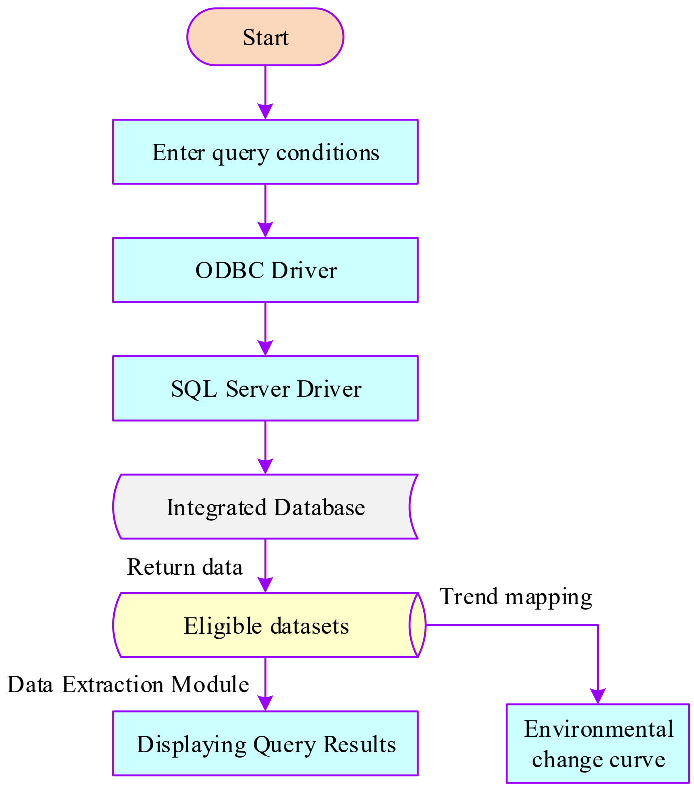


Fig. 4. Visual query system implementation process

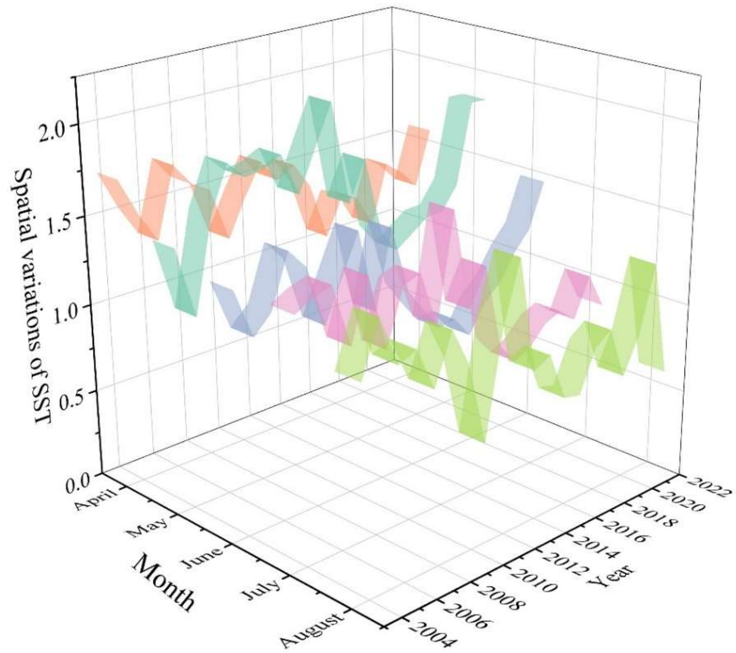
3. Multidimensional analysis of marine ecology

In this paper, the marine ecology of the Laizhou Bay Marine Ecological Reserve was analyzed multidimensionally over a 20-year period from 2003 to 2022, with the Laizhou Bay Marine Ecological Reserve as the research object.

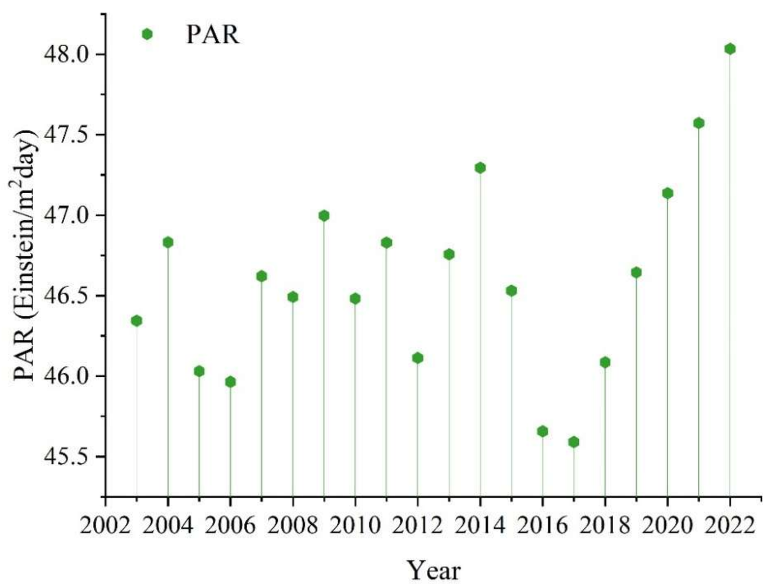
3.1. Sea surface temperature and photosynthetically active radiation

The temporal and spatial variations of sea surface temperature (SST) and photosynthetically active radiation (PAR) are shown in Fig. 5, where Fig. (a) shows the temporal variation of monthly mean SST in the study area from 2003 to 2022, and Fig. (b) shows the temporal variation of monthly mean PAR in the study area from 2002 to 2022.

Observation of Fig. 5 shows that after 2008, there is a small significant decrease in sea surface temperature in the Laizhou Bay region from April to July. A significant increase exists from May to August. Overall, the sea surface temperature from May to August has been increasing over the past 20 years, and the spatial difference has been reduced. It was found that from 2008 to 2022, there is an increasing trend in sea surface temperature from April to August, and the photosynthetically active radiation also shows an overall increasing trend.



(a) Temporal and spatial variations of sea surface temperature



(b) Temporal and spatial variations of photosynthetically active radiation

Fig. 5. Temporal and spatial variations of SST and PAR

3.2. *Sea surface salinity*

The sea surface salinity (SSS) of Laizhou Bay from 2003 to 2022 was statistically analyzed using the same method as that used to analyze SST, and the results are shown in Figure 6. It was found that compared with the pre-2008 period, the sea surface salinity in the study area after 2008 increased significantly from April to August, and the increased sea surface salinity was mainly concentrated in the near-shore sea area.

The sea surface salinity from April to September after 2008 showed an increasing trend, especially after 2019, and the increase became significantly larger. The spatial standard deviation of sea surface salinity in the study area from April to September from 2008 to 2021 decreased significantly, while the spatial difference of sea surface salinity from 2003 to 2007 did not have any significant change, and the change of spatial difference was not significant.

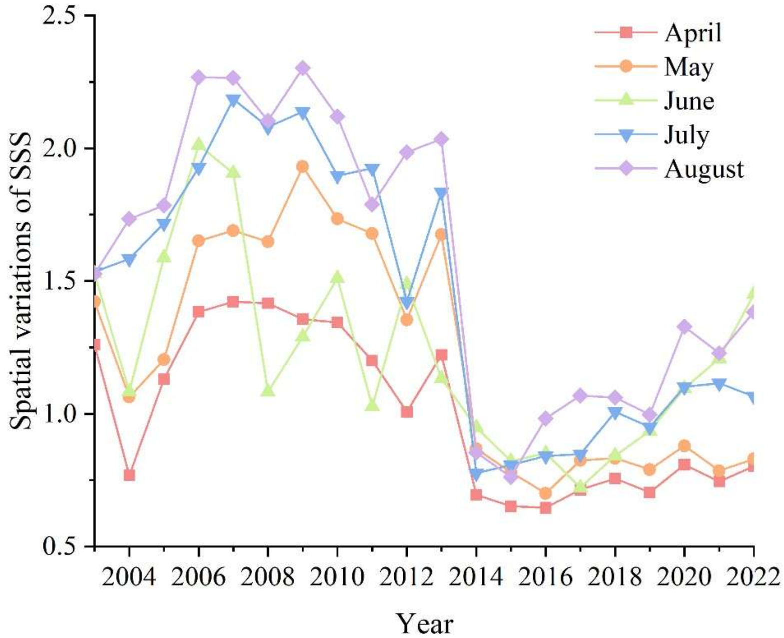


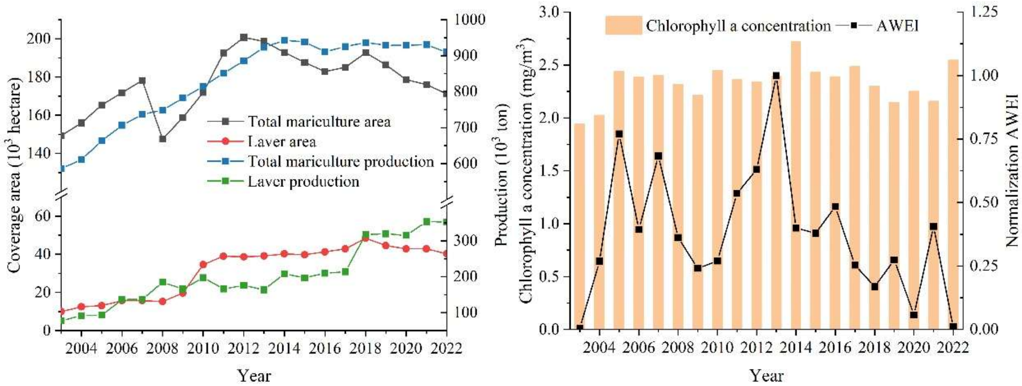
Fig. 6. Temporal and spatial variations of sea surface salinity

3.3. Degree of eutrophication

The eutrophication index method (E) is one of the most commonly used methods for evaluating eutrophication status in the field of marine environment. In order to evaluate the overall water quality status of regional waters based on different water quality classes, an area-weighted eutrophication index was proposed in this study. The eutrophication in the study area is shown in Fig. 7, Fig. (a) shows mariculture and Fig. (b) shows the eutrophication changes.

Influenced by land-based inputs, near-shore aquaculture and South Yellow Sea currents, the main exceeding indicators of pollution in the offshore of Laizhou Bay are inorganic salts and reactive phosphates. The total area of mariculture showed an increasing trend from 2003 to 2011 and a slight decreasing trend after 2011. The total aquaculture production showed a clear upward trend before 2013 and stabilized after 2013. The culture area of purple seaweed showed obvious expansion from 2008 to 2010, and basically maintained a steady state thereafter. Changes in the total production of nori can be roughly divided into three stages, with the first stage from 2003 to 2008 showing a slow increase, 2008 to 2016 basically maintaining a steady state, and 2017 to 2022, when the production went up to another level and maintained a steady state.

From 2003 to 2022, the polluted areas of different water quality classes in the Yellow Sea waters fluctuated annually without a clear trend, making it difficult to assess the overall eutrophication status of the water body. The application of the area-weighted eutrophication index (AWEI) facilitates the measurement of the overall eutrophication of the water body. The change of AWEI in the Yellow Sea calculated based on the water quality class area monitored in the summer of the previous years clearly shows the change process of nutrient pollution, the eutrophication of the water body showed an increasing trend from 2003 to 2013 and reached the peak (1.00), then the eutrophication showed an overall decreasing trend, and the AWEI of the region decreased to 0 in 2022. the eutrophication of seawater has been improved.



(a) Mariculture (b) Eutrophication

Fig. 7. Eutrophication in the study area

4. Results of the marine ecological assessment

4.1. *Construction of marine ecological assessment system*

According to the principles of wholeness, scientificity, simplicity and operability, through expert assessment and screening, combined with the actual situation of Laizhou Bay, the Laizhou Bay marine ecosystem health evaluation index system was constructed and empowered as shown in Table 1, which is mainly composed of two major categories of indicators, namely, environmental and biological indicators, and is divided into four levels, of which A is the functional level, and B-D is the indicator level.

Table 1. Laizhou bay marine ecosystem health evaluation index system

A layer	B layer	C layer	D layer
Environment index (A1) (0.425)	Water quality index (B1) (0.784)	DIN (C1) (0.254)	-
		DIP (C2) (0.254)	-
		Heavy metal (C3) (0.158)	-
		Rude oil (C4) (0.334)	-
	Sediment quality index (B2) (0.216)	Sediment organic matter (C5) (0.500)	-
		Sediment sulfide (C6) (0.500)	-
Biological index (A2) (0.575)	Structure index (B3) (0.486)	Phytoplankton (C7) (0.424)	Species diversity index (D1) (0.512)
			Species richness (D2) (0.209)
			Chlorophyll (D3) (0.279)
		Zooplankton (C8) (0.288)	Species diversity index (D4) (0.512)
			Species richness (D5) (0.209)
			Biomass (D6) (0.279)
		Benthos (C9) (0.288)	Species diversity index (D7) (0.512)
			Species richness (D8) (0.209)
			Biomass (D9) (0.279)
	Function index (B4) (0.257)	Primary productivity (C10) (1.000)	-
	Structure change index (B5) (0.257)	Phytoplankton biomass (Ch1/a)/ Zooplankton biomass (C11) (1.000)	-

With reference to the literature, the Integrated Health Index (IHI) of the marine ecosystem of Laizhou Bay was established, and the marine ecosystem of Laizhou Bay was categorized into three levels according to its IHI:

Healthy, $0.8 \leqslant IHI \leqslant 1.2$, indicates that the marine ecosystem of Laizhou Bay maintains its natural attributes, the biodiversity and ecosystem structure are basically stable, the main service functions are performed normally, and the ecological pressures caused by human activities are within the carrying capacity of the ecosystem.

Sub-healthy, $0.4 \leqslant IHI \leqslant 0.8$ or $1.2 \leqslant IHI \leqslant 1.6$, indicates that the natural attributes of the marine ecosystem in Laizhou Bay are basically maintained as normal, the biodiversity and ecosystem structure have changed to a certain extent, but the main ecological service functions can be performed as normal, and the ecological pressure caused by human activities is more than the ecosystem's carrying capacity, but the ecosystem can still recover itself as long as the pressure caused by human activities is lifted or weakened. However, as long as the pressure from human activities is lifted or reduced, the ecosystem will be able to recover itself.

Unhealthy, IHI $\leqslant$ 0.4 or IHI $\geqslant$ 1.6 indicates that the natural attributes of the marine ecosystem in Laizhou Bay have changed significantly, biodiversity and ecosystem structure have changed to a large extent, the main ecological service functions have been seriously degraded or lost, the ecological pressures caused by human activities have exceeded the range of the carrying capacity of the ecosystem, and even if the pressures of human activities are lifted or reduced, the ecosystem can hardly be restored in the short term. Even if the pressure of human activities is lifted or weakened, the ecosystem can hardly recover in a short period of time and must be supplemented with external energy.

4.2. Results of the marine ecological assessment

4.2.1. Results of the marine ecological assessment. Various indicators of marine ecology in Laizhou Bay were assessed and the results are shown in Table 2. The assessment indicators included inorganic nitrogen DIN (C1), inorganic phosphorus DIP (C2), oil (C4), phytoplankton species diversity index (D1), phytoplankton species richness index (D2), chlorophyll (D3), zooplankton species diversity index (D4), zooplankton species richness index (D5), zooplankton biomass (D6), primary productivity (C10), phytoplankton biomass/zooplankton biomass (C11).

From the calculation results in Table 2, the integrated health index (IHI) of the Laizhou Bay ecosystem was 0.27, 0.65 and 1.03 in 2003, 2012 and 2022, respectively, and the health index was gradually increasing, and the health status was “unhealthy”, “subhealthy” and “healthy”. The health status is “unhealthy”, “sub-healthy” and “healthy” respectively. This indicates that the marine ecology of Laizhou Bay has been gradually improved during the 20-year period from 2003 to 2022, and the ecological effect has been developing in a positive direction.

Table 2. Laizhou bay marine ecosystem integrated health index

Evaluation index	2003	2012	2022
C1	0.30	0.51	0.86
C2	0.27	0.42	1.27
C4	0.20	0.95	0.88
D1	0.33	0.56	0.84
D2	0.15	0.63	1.08
D3	0.34	0.67	1.17
D4	0.27	0.77	1.28
D5	0.28	0.55	1.15
D6	0.28	0.81	1.11
C10	0.23	0.88	0.84
C11	0.31	0.37	0.88
IHI	0.27	0.65	1.03

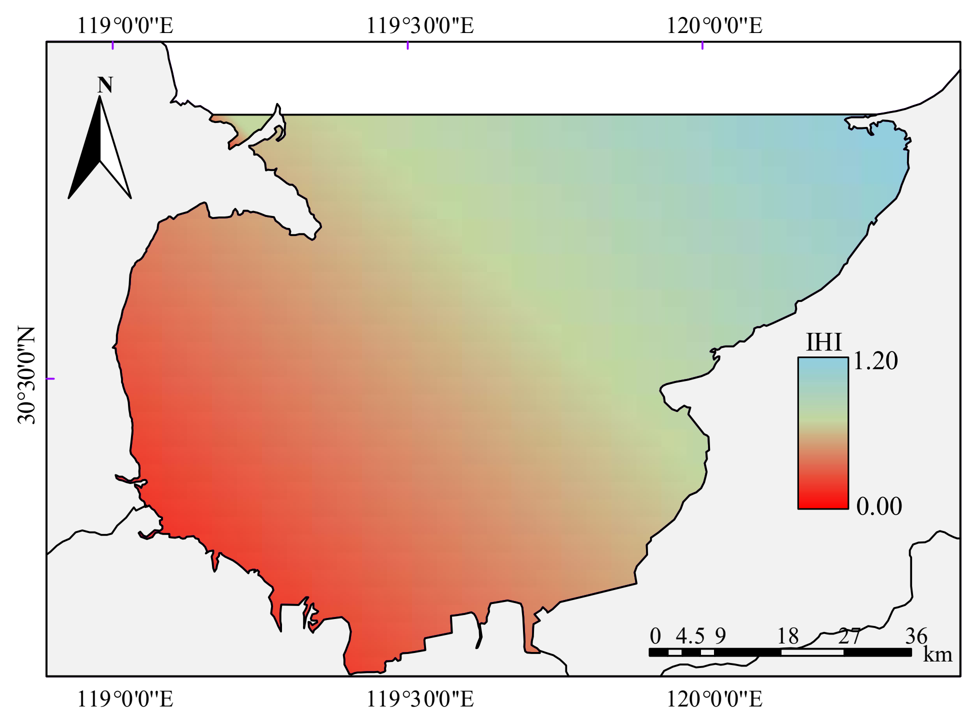
4.2.2. Spatial and temporal characteristics of the marine ecological state. Synthesizing the environmental elements and health state of Laizhou Bay, the spatial distribution of the health state of Laizhou Bay in 2003, 2012 and 2022 was plotted, and the spatial and temporal characteristics of the marine ecological state of Laizhou Bay are shown in Fig. 8, and Figs. (a) to (c) show the ecological health state of Laizhou Bay in 2003, 2012 and 2022, respectively.

The scores of the ecological health index of Laizhou Bay in 2003, 2012 and 2022 are 0.27, 0.65 and 1.03 respectively, indicating that the overall development of the marine ecosystem of Laizhou Bay is improving from unhealthy to healthy state.

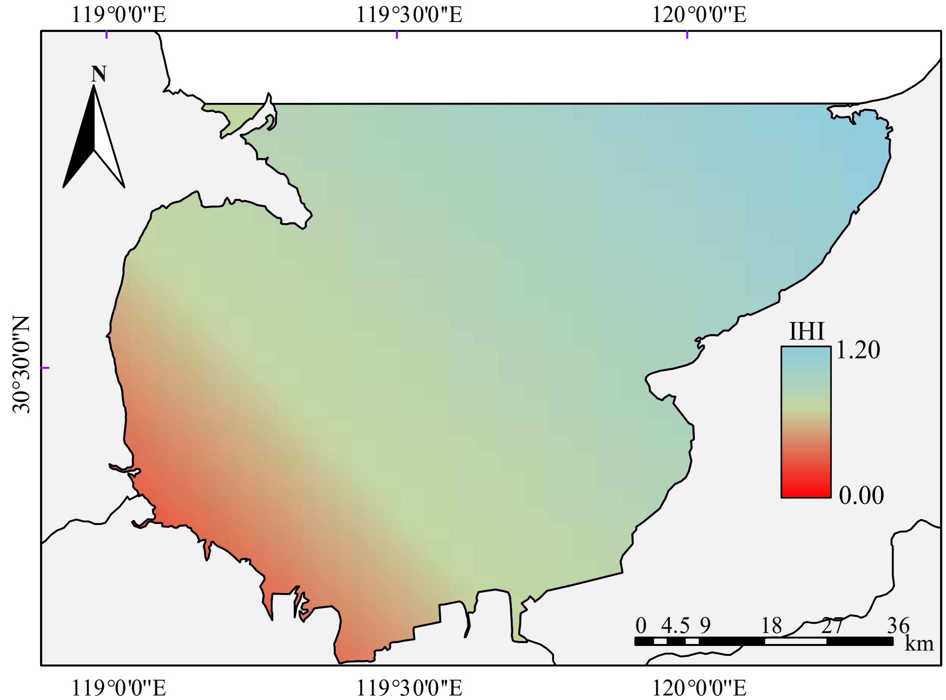
1) 2003: From the statistical results, the total area of healthy, sub-healthy and unhealthy zones in the sea area of Laizhou Bay is 1026, 2251 and 4685km2 respectively, accounting for 12.89%, 28.27% and 58.84% respectively, and the area of unhealthy zones is more than half of the overall area of the sea area, and the industrial and mining enterprises and living areas are gathered in the area, and relevant studies show that this area is significantly more affected than other areas by human activities is significantly higher than other areas.

2) In 2012, the total areas of healthy, unhealthy and unhealthy zones in Laizhou Bay were 1428, 4058, and 2476km2 respectively, accounting for 17.94%, 50.97%, and 30.09% respectively. Compared with 2003, the healthy and subhealthy areas of Laizhou Bay sea area expanded by 402 and 1807km2 respectively, and the total area of unhealthy area shrunk by 28.75%. The overall ecological effect has been greatly improved. Sub-healthy area is the largest area of Laizhou Bay in 2012, the ecosystem in this region is in the transition state from healthy to unhealthy, and human activities have a certain impact on the marine ecosystem, such as the blue oval in the figure is the concentrated area of aquaculture, industrial and residential land use is dense, and human activities are frequent, coupled with land-based discharges from the rivers and outfalls, which is an important factor in the deterioration of ecosystems in this region, combining the Before the chlorophyll, nitrate nitrogen and other indicators of the distribution pattern analysis, the region should focus on preventing and controlling the risk of eutrophication of water bodies.

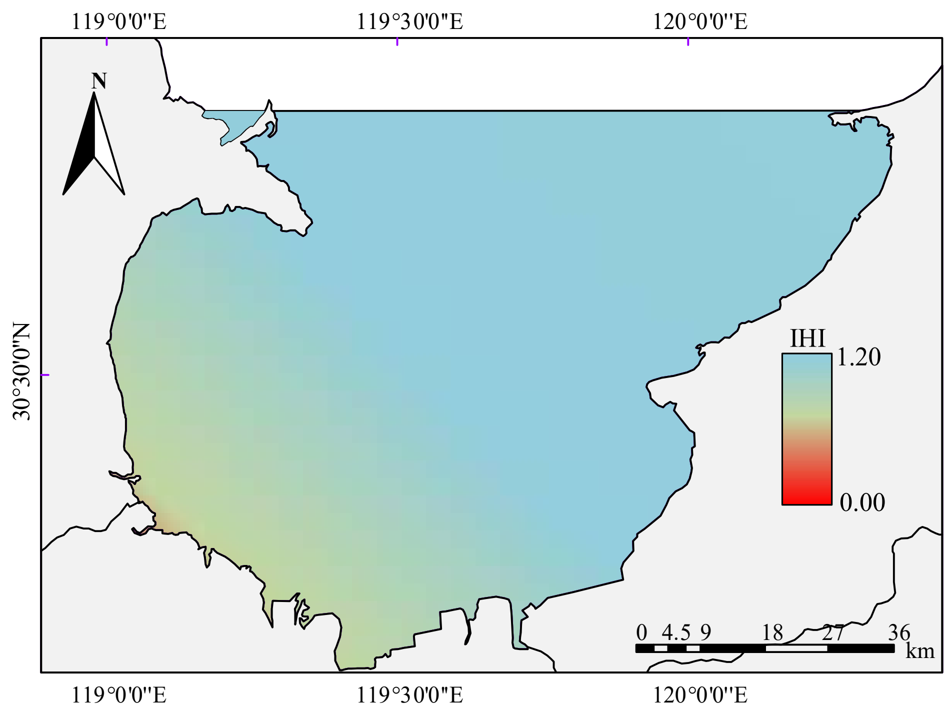
3) 2022: The total areas of healthy, subhealthy and unhealthy zones in Laizhou Bay waters are 5,369, 2,112 and 481km2 respectively, accounting for 67.43%, 26.53% and 6.04% respectively. The area of healthy zone is more than half of the total area, which is mainly concentrated in the Yantai nearshore waters on the east side of the study area, and the environmental quality of the area connected to the Bohai Sea in the northern part of Laizhou Bay is relatively good. From the satellite remote sensing images, it can also be seen that the eastern part of Laizhou Bay has fewer human activities, there are no urban construction sites and residential areas near the shore, and there are not many rivers entering the sea, so the pollutants discharged from land-based sources have a limited impact on the marine ecology. The total area of unhealthy zones will further decrease sharply in 2022, accounting for 6.04% of the total area, and the ecological environment of the Bay will become significantly better.



(a) 2003 ecosystem health condition



(b) 2012 ecosystem health condition



(c) 2022 ecosystem health condition

Fig. 8. Laizhou bay ecosystem health condition

5. Conclusion

This paper builds a remote sensing monitoring system for the marine ecological reserve and analyzes the marine ecology in multiple dimensions through the monitoring data. A marine ecological health assessment index system is constructed to assess the ecological health of the study area, and the spatial and temporal characteristics of ecological health are further analyzed.

Overall sea surface temperature and photosynthetically active radiation in the Laizhou Bay region showed an increasing trend during 2003-2022.Sea surface salinity from April to September showed an increasing trend after 2008, and the increase after 2019 became significantly larger. The total area of mariculture and the total area of zizyphus culture were generally on the rise during the 20-year period. The eutrophication of the water body showed an increasing trend from 2003 to 2013, and reached a peak (1.00) in 2013, and then the eutrophication phenomenon was alleviated, and the AWEI of the region decreased to 0 in 2022.The integrated health index (IHI) of the Laizhou Bay ecosystem in 2003, 2012, and 2022 were 0.27, 0.65, and 1.03, respectively, and the state of health gradually shifted from “unhealthy” to “healthy”. The health status gradually changed from “unhealthy” to “healthy”. During the 20-year period, the unhealthy and subhealthy areas in Laizhou Bay have shrunk by 52.80% and 1.74%, respectively, and the healthy area has expanded by 54.54%.

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