ANNOTATION

to the dissertation for the degree of Doctor of Philosophy

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IMPROVEMENT OF THE METHODOLOGY OF MONITORING THE CASPIAN SEA COASTLINE BASED ON EARTH REMOTE SENSING DATA

This dissertation research is devoted to the current problem of monitoring the Caspian Sea coastline using Earth remote sensing (ERS) data. The Caspian Sea region is unique in its natural features. The Caspian basin is one of the largest endorheic areas on the planet, located in various landscape zones, has rare sturgeon fish stocks and valuable endemic biodiversity.

In the oil production areas of Kazakhstan on the north-eastern coast of the Caspian Sea, specific lakes have formed as a result of the discharge of associated highly mineralized underground waters (extracted during oil production) and oil spills. They pose a terrible threat to the Caspian ecosystems, since catastrophic pollution of the sea will occur with wind surges of Caspian waters and, especially, in the event of a further rise in sea level.

The transition from traditional methods to modern technologies using methods and means of space geodesy has led to the development and widespread use of global navigation satellite systems (GNSS). Along with this, recently the tasks of monitoring the natural environment and forecasting possible changes in the natural environment of various regions have come to the fore. This explains the special attention paid to the study of the dynamics of geosystems, processes occurring in the earth's crust and the creation of dynamic maps of natural phenomena.

Purpose and objectives of the study

The purpose of this work is to improve the methodology for monitoring changes in the Caspian Sea coastline using Earth remote sensing (ERS) data, ensuring high accuracy, efficiency and information content for analyzing coastal zone dynamics and making management decisions. The following tasks were set to achieve the goal:

– Review and analyze modern approaches to coastline monitoring, including the use of satellite data, geographic information systems (GIS) and coastal zone change models.

– Select the most suitable satellite platforms and sensors for monitoring the Caspian Sea coastline, evaluate their resolution, periodicity and spectral characteristics.

– Create algorithms for processing satellite data, including automatic classification, change detection and integration of multi-temporal data.

– Create an improved methodology for monitoring the Caspian Sea coastline based on the use of modern Earth remote sensing data.

Research methods

To accomplish the set tasks, methods of remote sensing of the Earth were used. They included: analysis of existing domestic and foreign methods of monitoring water bodies; justification of the choice of scientifically based methods of performing measurements using equipment of satellite systems, space data Landsat, Sentinel.

Results

The coastline detection process was automated using the Otsu thresholding method applied to Landsat 5, 7, and 8 Tier 1 products from the Landsat TM sensor. Tier 1 products were chosen because they meet the stringent geometric and radiometric quality requirements needed for accurate analysis.

All data processing was performed on the Google Earth Engine (GEE) platform, leveraging cloud computing power to optimize local resources and improve overall processing efficiency.

The methodology proved to be highly time and cost effective due to the use of free and open source software (FOSS) and the GEE cloud infrastructure.

The analysis was conducted over several years with two main study areas: Atyrau and the Mangystau region. Due to their geographic proximity, the Aktau and Fort Shevchenko regions were combined into one larger study area, the Mangystau region. This approach ensured comprehensive coverage of the region and maintained spatial consistency throughout the analysis. Deep Learning allows analyzing large amounts of data, such as satellite images, time series, geographic data, in this regard, the dissertation substantiates the need for further development of artificial intelligence and machine learning algorithms.

Scientific novelty

1. Integrated comprehensive approach to monitoring the Caspian Sea coastline based on the use of traditional method data and modern Earth remote sensing data.

2. Improved algorithms for automatic classification and analysis of satellite images, allowing for effective detection of changes in the coastline caused by anthropogenic and natural factors.

3. A system for long-term monitoring of changes in the coastline using machine learning techniques and time series analysis of remote sensing data is proposed.

The following scientific provisions are submitted for defense:

1. An integrated approach to monitoring the coastline of the Caspian Sea has been developed, based on the use of data from the traditional method and modern data from remote sensing of the Earth.

2. Algorithms for automatic classification and analysis of satellite images have been developed to effectively identify changes in the coastline caused by anthropogenic and natural factors.

3. An advanced method for automated processing of satellite data and machine learning with time series analysis, providing comparison of changes in multi-temporal data, assessment of the rate and direction of changes in the coastal zone.

The practical significance of the work is as follows:

1. The developed methodology allows for prompt and highly accurate detection of changes in the coastline, providing access to up-to-date information for government agencies, environmental services and scientific organizations.

2. The results obtained can be used to assess the impact of natural and anthropogenic factors on coastal areas, as well as to develop measures to minimize environmental risks.

3. The resulting data on shoreline dynamics can be used to inform adaptation strategies for coastal communities and infrastructure to sea level changes and other climate challenges.

4. The use of modern technologies for processing remote sensing data, including the use of satellite data and geographic information systems (GIS), allows for prompt decision-making when monitoring the objects under study.

Validity and reliability

The validity and reliability of scientific provisions, conclusions and recommendations are confirmed by a large number of primary data for the period 1990-2024, the convergence of forecasting results with real data. The author's personal contribution is the analysis of domestic and international experience in monitoring the coastline using modern technologies, data processing using satellite systems equipment, Landsat, Sentinel space data.

Publications and testing

Based on the materials of the dissertation, 7 printed works were published, including:

– One article in the rating journal of the National Academy of Sciences of the Republic of Kazakhstan, Series of geology and technical sciences (Scopus Q3 database)

Three articles in publications recommended by the Committee for Control in the Sphere of Education and Science of the Republic of Kazakhstan (Ministry of Science and Higher Education of the Republic of Kazakhstan)

– Three articles in collections of international conferences, forums and congresses.

The research results have been implemented in the educational process, which is confirmed by the relevant acts.

Conclusions:

Improving the methodology for monitoring changes in the Caspian Sea coastline using Earth remote sensing (ERS) data ensures high accuracy, efficiency and information content for analyzing the dynamics of the coastal zone, and also allows covering a large area of the object under study. Based on the research and development carried out, the following conclusions can be drawn:

1. Testing of the interpretation methods showed that the best way to recognize water surfaces for the Caspian Sea is to calculate the MNDWI index, which has a minimum value of the root-mean-square error.

2. The developed technological scheme for monitoring the coastline based on Earth remote sensing data allows for automatic extraction of the coastline.

3. The methodology turned out to be highly effective in terms of time and cost due to the use of free and open source software (FOSS) and the GEE cloud infrastructure.

4. The inclusion of unsupervised K-means clustering and supervised Random Forest classification algorithms in Sentinel-2 data processing made it possible to obtain highly accurate cartographic information on the coastline dynamics.

5. The improved approach demonstrates high potential for long-term monitoring of the coastal zone and can be adapted to analyze coastal dynamics in various coastal regions. Further research could focus on integrating additional spectral and topographic data, as well as improving machine learning algorithms to improve the accuracy of shoreline classification and account for seasonal variations.

Taken together, these findings highlight the importance and effectiveness of implementing modern geospatial technologies and analysis methods for monitoring water bodies. These improvements not only improve the accuracy and efficiency of existing methods, but also provide new tools for research and practical applications in various fields.

Structure and volume of the dissertation

The dissertation consists of an introduction, four chapters, a conclusion and a list of references. The work is presented on 98 pages of typewritten text, contains 14 tables, 55 figures, a list of references from 120 titles.

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