

ANNOTATION

Dissertation for the degree of Doctor of Philosophy (Ph.D)
In specialty 6D061000 – Hydrology

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Research of wind waves in the Caspian Sea based on numerical modeling

Engineering and development of oil and gas fields in the Caspian region, year-round shipping at sea (for tourism, and cargo transportation), and the need to preserve biodiversity have led to an increasing interest in a comprehensive study of the Caspian Sea, including hydrometeorological processes (surge phenomena, wind waves, ice processes, currents).

Dissertation is devoted to the study of wind waves in the Kazakh part of the Caspian Sea in a long-term retrospective period and its possible changes in the future.

The **object of research** is the Kazakh part of the Caspian Sea.

The **subject** of the research is the dynamics of changes in the characteristics of wind waves in the open waters of the Caspian Sea.

The **aim of the research work** is to study the process of wind waves at sea, and the calculation of its spatio-temporal change at present and in the future based on numerical modeling using the SWAN spectral-wave model and remote sensing data. To achieve this I goal, the following objectives have been identified:

- Analysis of thermal and hydrodynamic processes in the waters of the Caspian Sea on the basis of observed data;
- Development of the «Catalogue of strong waves» based on wind waves data from observation stations and posts;
- Retrospective calculations of the characteristics of wind waves using numerical modeling over a multi-year period and determination of features of spatial and temporal variability of parameters of wind waves, inter-annual variability, and analysis of regime characteristics;
- Statistical evaluation of calculated data compared to observations;
- Calculation of wave height based on CMIP6 future climate projection data up to 2050 for SSP1.26 and SSP5.85 climate change scenarios;
- Creation of maps of spatio-temporal distribution of wave height and direction for a long-term retrospective period and wave height for the future until 2050;
- Zoning of the territory of the Kazakh part of the Caspian Sea according to the degree of waves.

The sources of the research. Archival and literary materials, including - data from the catalog «Annual data on the regime of the Caspian Sea, Kazakhstan coast», materials of RSE «Kazhydromet» Ministry of Ecology and natural resources of the Republic of Kazakhstan, data of remote sensing of the Earth, including real-time data, altimeter satellites, data of climatic models of the NEX-GDDP-CMIP6 dataset, cartographic material.

Research methodological base. The approaches used in the dissertation work are based on the use of numerical modeling to describe wave processes in the sea together with a statistical analysis of current coastal observation data. The obtained actual, stock, and cartographic materials were processed, and statistical characteristics were calculated. Comparative and descriptive analysis of the data was carried out. The accuracy of the data was assessed using statistical criteria, such as the coefficient of correlation, determination, efficiency, agreement index, mean absolute, and standard error. To calculate the characteristics of wind waves, using a spectral wave model SWAN, for the preparation of the input parameters of which the R programming language, the DHI.Generic.NetCDF.MIKE program. As wind forcing, wind data from the ERA5 reanalysis with a resolution of 0.250 was used. Climate projections for the future was derived for climate change scenarios from SSP1.26, and SSP5.85. According to the collected various input data, thematic maps were created in the Qgis program.

Relevance of the dissertation research. The water area of the Caspian Sea is within the scope of the country's strategic interests in economic, transport, and infrastructure terms. In 1963, the port of Aktau was created near the sea coast, as part of the execution of the decree of President "Nurly Zhol - the path to the future" and the implementation of the "New Silk Road" project, the port of Kuryk was opened in 2016.

In turn, the oil and gas industry of the republic is successfully developing in the Caspian region and there are three largest oil and gas fields: Tengiz, Karachaganak, and Kashagan. Transportation of oil for export is carried out through various oil pipelines, also through the port of Aktau (along the transportation route Aktau-Baku, Aktau-Makhachkala).

Coastal areas are subjected to the cumulative action of several factors: rising or falling sea levels, increased frequency of natural disasters, and coastal erosion. The development of technical means for the development of the marine area (oil and gas production), the marine fleet, and the need to preserve biodiversity has led to an increasing interest in a comprehensive study of the Caspian Sea, including hydrometeorological processes.

In this regard, information on dangerous and natural hydrometeorological phenomena (strong winds, strong waves, surge fluctuations in sea level, etc.) is in demand when working at sea, designing structures in open waters and on the coast, to ensure safe navigation of civil and military fleets.

Storm surges can cause great economic damage. In addition, the study of the wave regime is necessary for predicting changes in wave characteristics in order to ensure the safety of navigation at sea and for the accumulation of field data on waves used in theoretical studies in this area. This determines the relevance of the study of wave processes.

Performing any calculations that are related to wave parameters is hampered by the lack of long series of observations, which in turn are carried out visually, therefore, in most cases, wave characteristics are calculated as a result of mathematical or numerical modeling.

The scientific novelty of the research is defined as follows:

- for the first time, a qualitative and quantitative assessment of spatio-temporal changes in the characteristics of wind and waves in the Kazakh sector of the Caspian Sea was carried out according to coastal observations, remote sensing data (altimetry, reanalysis), calculated model data (SWAN, ECWAM);
- zoning maps of wave height changes in the Caspian Sea were created based on the results of numerical modeling using the SWAN model and wind characteristics according to ERA5 reanalysis data for 1959–2021. and climate projections of CMIP6 models for the future up to 2050.
- for the first time, a long-term forecast of changes in wave height up to 2050 was compiled for the main observation points in the Kazakh sector of the Caspian Sea;
- for the first time, developed a map of the zoning of the water area of the Kazakh sector of the Caspian Sea according to the degree of waves.

The main provisions for defended:

- New ideas about the nature of the wind regime of the Caspian Sea according to coastal observations and remote sensing data: a trend towards a decrease in the average wind speed was revealed; with the predominance of eastern, southeastern, and northern wind directions and their number in the northeastern part of the sea;
- The development of the "Catalogue of strong waves", made it possible to assess the features of wave characteristics in the Kazakhstani sector of the Caspian Sea and the features of their seasonal distribution;
- New ideas about the nature of waves in the open waters of the Kazakhstani sector of the Caspian Sea, identified on the basis of numerical modeling using ERA5 reanalysis data and CMIP6 climate change models;
- Maps of zoning of the Caspian Sea water area according to the degree of excitement were built.

Scientific and practical significance of research work. The scientific significance lies in obtaining new scientific knowledge and data for understanding the mechanism and identifying the features of wind waves in the water area of the Kazakhstani sector of the Caspian Sea in the present and in the future until 2050 under the conditions of climate change.

The results of the study can be used in the design of the construction of coastal structures, the definition of navigation routes at sea, etc.

The economic effect is to ensure the safety of the population from the influence of natural phenomena and related natural and man-made emergencies.

The personal contribution of the author to the solution of the tasks of the dissertation research is:

- In conducting a qualitative and quantitative assessment of spatial and temporal changes in the characteristics of wind and waves in the Kazakh sector of the Caspian Sea;
- In the development and creation of a series of maps, and schemes of functional zoning of areas;

- In the preparation and publication of the obtained scientific results on the subject of the study in rating journals. The main provisions of scientific articles are reflected in the dissertation sections for Ph.D.

Approbation of work. The main results of the dissertation research were presented at:

- 17th CAS-TWAS-WMO Forum (2018, Beijing, China);
- International Symposium on Water and Land Resources in Central Asia (2018, Almaty, Kazakhstan);
- Lomonosov Conference (2019, Moscow, Russia);
- II All-Russian Scientific and Practical Conference dedicated to the 55th anniversary of the Department of Hydrology and Environmental Management of IGU (2019, Irkutsk, Russia);
- International Scientific Conference "Climate Change in the Caspian Sea Region" (2021, Moscow, Russia);
- IV International scientific conference Development of waterways in the context of global climate change on the territory of the Russian Federation (Eurasia) ("Hazardous Phenomena - IV") in memory of Corresponding Member of the Russian Academy of Sciences D.G. (2022, Rostov-on-Don, Russia).
- International Scientific Conference «Global Challenges for Global Science II» (2022, Sofia, Bulgaria)

Based on the materials of the dissertation research, 23 papers were published, including 4 articles in a journal included in the Scopus database, 6 articles in republican scientific journals from the list of the Committee for Control in Education and Science of the Ministry of Education and Science of the Republic of Kazakhstan, 11 articles in the material of international conferences, 2 articles in scientific journals.

Dissertation structure. The dissertation is presented on 159 pages and consists of definitions, designations and abbreviations, an introduction, 5 sections, a conclusion and a list of references from 180 titles, 53 of which are in foreign languages; contains 28 tables, 47 figures and 3 appendices.