DEVELOPMENT OF THE INVESTIGATION APPROACH TO WINTER MULTI-HAZARDS FOR CLOSED RESERVOIRS ON THE EXAMPLE OF THE CASPIAN SEA

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ABSTRACT

This article describes a study approach of winter multi-hazards and assessment of their impact on shores, coastal infrastructure and hydraulic structures in the closed water bodies on an example of the Caspian Sea. The whole approach is divided into four main stages. The first stage is devoted to the analysis of existing criteria for hazardous natural phenomena. The second stage is devoted to the reconstruction (hidcasting) of winter multi-hazards. At the third stage, the classification of winter periods depending on the amount of simultaneous occurrence of adverse or dangerous hydrometeorological phenomena is performed. At the final fourth stage the assessment of surge phenomena and dynamic wave impact on coastal territory is carried out. The approach introduced in this article combines methods and mathematical models proved in the world practice into a single fundamentally new method for studying winter multi-hazards and provides new fundamental results. In the future, it may find practical application for short-term forecasting and early detection of emergencies.

Keywords: Caspian Sea, multi-hazards assessment approach, wind wave, storm surge, extreme ice phenomenon

INTRODUCTION

The beginning of the 21st century in the southern macro-region of Russia was marked by a number of weather cataclysms during winter periods. Abnormally low air temperatures, e.g. in 2006 and 2012, led to the formation of torosses of up to 2 m in the Azov Sea, the Black Sea froze up to Bulgaria and the Caspian Sea up to Makhachkala; the number of extreme surges and storm surges increased. In the entire region the annual amplitude of air temperature has increased substantially.

In this regard, attention of scientists has been attracted to the research of the formation mechanisms and prediction of dangerous natural phenomena. But the main emphasis in this case is only made on either a rigorously fundamental study and documentation of individual phenomena or on the development of methods for predicting them. So for example, in the scientific literature there is very few detailed information about dangerous surge phenomena, except for the catastrophic upserge of 1952 which is described in detail in the works of the last century [5], [9]. There are numerous articles are devoted to the features and main regularities of the ice regime of the Caspian Sea. Those works [1], [2], [3], [4] describe formation and destruction conditions of ice, long-term variability of the ice-time and dangerous ice phenomena in the Caspian Sea negatively affecting shipping. The monograph [6] gives a complete description of the ice regime of the sea. It gives information on the factors determining ice conditions, typing of winters according to the degree of severity as well as charts of the ice situation for each winter type. The work describes ice formation, growth, propagation and clearing. One of the most complete works on the wind wave regime and wave climate description of the sea can be considered [10]. At the same time, when forecasting and preventing adverse and dangerous phenomena the executive authorities, the Ministry of Emergency Situations and emergency services are guided by the "Instruction for the preparation and transmission of storm alerts to monitoring units. RD 52.04.563-2013" (introduced 07/04/2014) containing no single criterion for the occurrence of a dangerous phenomenon with a cumulative effect, i.e. simultaneous impact of two or more dangerous phenomena.

Against the backdrop of intensive technological platform development and improvement of research and forecasting methods an irreparable damage caused by natural disasters still sometimes occurs. This is not the way it should be. It is necessary to analyze and consider the lessons of the history and pay due attention to new fundamental directions in the study of dangerous natural phenomena, such as multi-hazards, the results of which can later be introduced into practice.

In our opinion, the problem described in Russia has not yet been solved and requires careful attention. Particularly important is the study of winter multi-hazards (WMH) in reservoirs with no connection to oceans, such as the Caspian Sea, during the period of instrumental observations (since 1900) and their impact on the coast, coastal infrastructure and hydraulic structures. The approach introduced in this article combines methods and mathematical models proved in the world practice into a single fundamentally new method for studying winter multi-hazards and provides new fundamental results. In the future, it may find practical application for short-term forecasting and early detection of emergencies, not only in the Caspian Sea but also in other water areas.

DESCRIPTION OF THE APPROACH DEVELOPED

The whole approach is divided into four main stages (fig. 1).

Stage 1. Hazard criteria currently in use for each natural phenomenon are determined on the basis of classification techniques already described in the literature:

- short-term surging fluctuations of the Caspian Sea level,

- storms,

- extreme ice phenomena,

- wave load on the coast and infrastructure facilities.

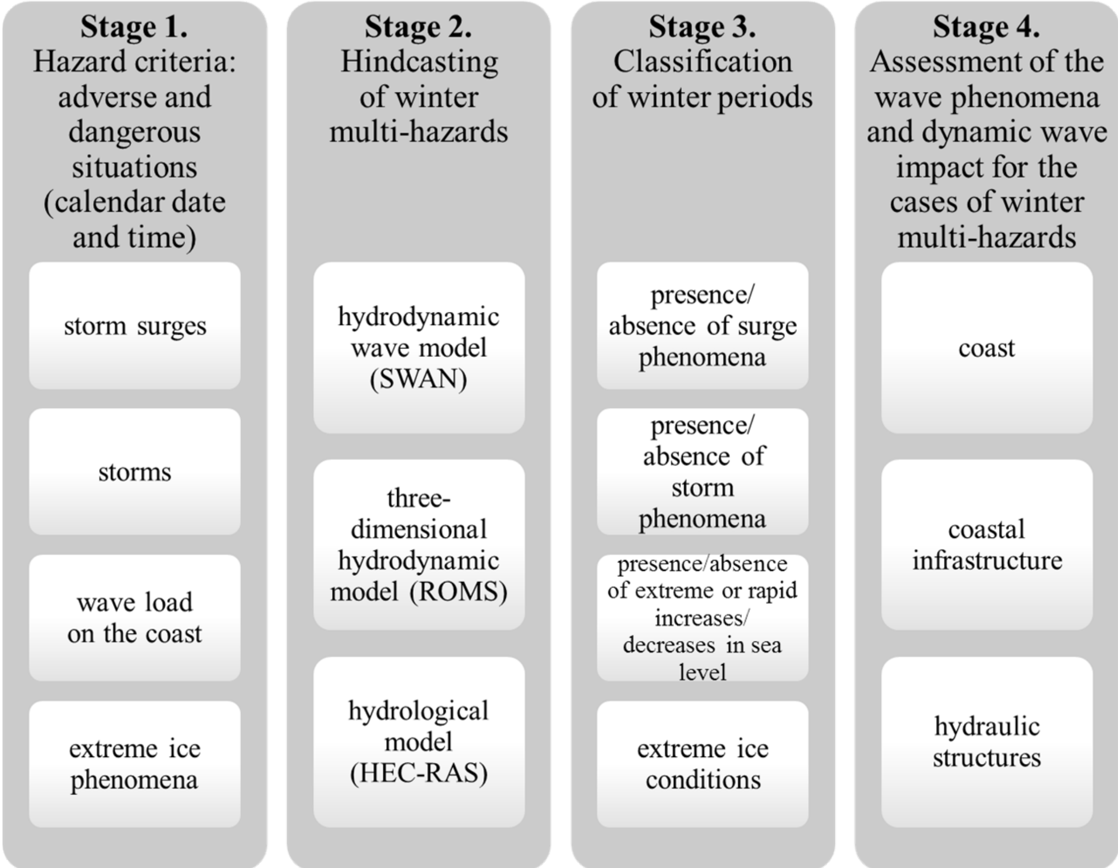

Figure 1. Main stages of the investigation approach to winter multi-hazards for closed reservoirs

On the basis of these criteria, cases of adverse and dangerous situations in the Caspian Sea (calendar date and time) of each phenomenon are identified separately in the century rows of hydrometeorological information. A particular attention at this should be paid to the dates with a sharp change in temperature conditions and simultaneous exposure to strong winds. On such external influences, there is the greatest occurrence probability of ice surges or ice storms.

Stage 2 is devoted to the reconstruction (hidcasting) winter multi-hazards identified at stage 1 using mathematical models. Three mathematical models form the basis:

- A hydrodynamic wave model. The spectral wave model SWAN (Simulating WAves Nearshore [11]), adapted to the conditions of the Caspian Sea was used in this work. SWAN calculates the wave parameters (height of significant waves, average length, height and wave period).

- A three-dimensional hydrodynamic model. ROMS model (Regional Ocean Modeling System [8]) adapted to the conditions of the Caspian Sea was used in this work for the calculation of currents.

- A hydrological model. HEC-RAS model (U.S. Army Corps of Engineers Institute for Water Resources (CEIWR) Hydrologic Engineering Center (HEC) [7] together with the ArcGIS ESRI software package were used in this work. By means of this complex the calculation of flooding zones on coastal territories and the delta of the Volga river as a result of short-term (surge) level rises were carried out.

All the listed models are united in a single calculation system according to the scheme ROMS → SWAN (the results of independent calculations of the ROMS model are fed into the SWAN model) and ROMS → HEC-RAS (the calculations results of the ROMS model are fed to the HEC-RAS model). For the Northern Caspian and individual coastal areas the calculation is performed using nested grids. The main grid of the Caspian Sea with a spatial resolution of 1x1 km and nested grids of 0.001x0.001 km were used as input parameters. The temporal discreteness of calculations is 30 minutes.

At this stage, the initial series (input data) of historical hydrometeorological information for mathematical models are formed and the quality of the initial data is controlled in order to minimize possible errors.

The fulfillment of calculation series aimed at obtaining a reanalysis of the isolated cases of development and degeneration of dangerous and unfavorable winter natural phenomena allows restoring the fields and characteristics of waves, sea level, area and boundaries of flooded areas and field currents. The models take into account changes in the position of the shoreline depending on sea level, morphometric characteristics and ice edge position.

Stage 3. At the third stage, the classification of winter periods depending on the amount of simultaneous occurrence of adverse or dangerous hydrometeorological phenomena is performed:

- presence/absence of surge phenomena;

- presence/absence of storm phenomena;

- presence/absence of extreme or rapid increases/decreases in sea level;

- extreme ice conditions: winter severity (severe or mild), abnormally cold weather, severe frosts, sudden changes in air temperature (sharp warming or fall of temperature) and ice cover characteristics (ice cover, terms of ice formation and destruction, dates of maximum ice cover development).

For each class, criteria indicating the degree of threat of a multi-hazard phenomenon (an unfavorable and dangerous phenomenon) are defined.

Stage 4. At the final fourth stage, an assessment of the wave phenomena and dynamic wave impact for the cases of winter multi-hazards on the coast, coastal infrastructure and hydraulic structures is carried out using the mathematical SWASH model (Simulating WAves till SHore) and the program module for dynamic impact on the shore developed by the Marine Hydrophysical Institute (Sevastopol) and mathematical SWASH model (Simulating WAves till SHore).

CONCLUSION

An analytical review of the current state of the study of the problem "method for studying winter multi-hazards for closed water reservoirs" was performed. It is shown that the problem described has not yet been solved in Russia and requires an attentive attitude.

The paper presents an approach to the study of winter multi-hazards which makes it possible to obtain reconstruction (hidcasting) of these cases using mathematical models, the classification of winter periods depending on the number of simultaneously occurring hazardous phenomena and the assessment of their impact on coastal infrastructure.

This approach is universal and can be applied not only to enclosed water bodies such as the Caspian Sea. The approach has already been successfully applied to the shallow water area of the Sea of Azov [12].

The method proposed allows approaching in a new way not only the forecasting of dangerous natural phenomena but also the future climate changes since dangerous natural phenomena must be considered in the aggregate. This will allow for reassessing the extreme situations already observed, improving existing representations and help to refine the predictive mathematical models.

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REFERENCES

[1] Bukharitsin P.I., Icing on the Caspian Sea, Bulletin of the Astrakhan State Technical University, No. 6, 2007.

[2] Bukharitsin P.I., Dozortseva Yu.V., Features of ice conditions on the Lower Volga and the Northern Caspian in the moderate winter of 2006, Southern Russian Geology Bulletin, Geography and Global Energy, Russia, No. 1, 2006.

[3] Bukharitsin P.I., Comparative characteristics of long-term ice cover variability of the Northern part of the Caspian and Azov Seas, Bulletin of the Astrakhan State Technical University, Russia, No. 3, 2008.

[4] Bukharitsin P.I. Regularities of the ice cover formation of the Northern part of the Caspian Sea, South-Russian Geology Bulletin, Geography and Global Energy, Russia, No. 3, pp. 45-64, 2006.

[5] Hydrometeorology and hydrochemistry of the seas. Vol. VI The Caspian Sea. Issue 1. Hydrometeorological conditions. Russia, 360 p., 1992.

[6] Dumanskaya I.O. Ice conditions of the seas of the European part of Russia, Russia, 605 p, 2014.

[7] Gary W. Brunner HEC-RAS, River Analysis System. Hydraulic Reference Manual, (CPD-69) /, Version 5.0. February, 547 p, 2016,

[8] K. Hedstrom. Technical Manual for a Coupled Sea-Ice/Ocean Circulation Model (Version 4), U.S. Dept. of the Interior, Bureau of Ocean Energy Management, Alaska OCS Region. OCS Study BOEM 2016-037, 176 pp, 2016.

[9] Koshinsky S.D., Flood conditions in the North-Western Caspian on 10-13 November, 1952, Proceedings of the West Siberian Regional Research Institute, Russia, issue 50, pp. 63-74, 1981.

[10] Lopatukhin L.I., Bukhanovsky A.V., Degtyarev A.B., Rozhkov V.A. Reference data on the wind and wave regime in the Barents, Okhotsk and Caspian seas, Russian Maritime Register of Shipping, Russia, 214 p, 2003.

[11] SWAN. Technical documentation. - Delft University of Technology, Faculty of Civil Eng. and Geosciences, Environmental Fluid Mechanics Section. – 2006. – 88p.

[12] Yaitskaya N., Tretyakova I., Mathematical Modeling Of Dangerous Storm And Surge Phenomena In The Basin Of The Sea Of Azov (March 24, 2013), 16th International Multidisciplinary Scientific GeoConference SGEM 2016, Bulgaria, Book3 Vol. 1, 481-488 pp., 2016.