ANNOTATION
of Dissertation work for the degree of Doctor of Philosophy (Ph.D) on specialty «8D05204 – Meteorology»

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Study of changes in snow water equivalent in the Esil and Nura-Sarysu basins under climate change conditions

Sustainable development of a country in the context of climate change is becoming an increasingly important factor in today's world. Food and water security are key aspects of sustainable development. Water resources and agriculture have an important role in development and economy in the Esil and Nura-Sarysu water basins, as they have the highest agro-climatic potential. In the studied basins, water resources cover aspects of water supply for different sectors such as industry, agriculture and especially important for drinking water supply to the population. In this regard, scientific and methodological support of sustainability in agriculture and water resources assessments and, in particular, studies of changes in snow cover moisture reserves as the main source of water resources formation in the study area under climate change conditions are of high relevance. The results of this study can serve as a scientific and methodological basis for regulation and optimization of water resources use to meet the needs of regional development of the Esil and Nura-Sarysu water basins, as well as in the development of various government strategies and plans to improve water resources management and adaptation to climate change.

The dissertation is devoted to the study of the dynamics of changes in the moisture content of the snow cover of the Esil and Nura-Sarysu basins under the conditions of modern climate change and its possible changes in the future.

The object of the study is Esil and Nura-Sarysu water basins.

Subject of the study - dynamics of changes in snow water equivalent.

The aim of the study is to assess the dynamics of current changes in snow water equivalent and their future changes under climate change conditions.

To achieve the goal, the following objectives were set:

- To assess climatic features and modern climatic changes of the territory;
- To study the dynamics, spatial and temporal changes in snow water equivalent;
- Modeling of snow water equivalent using MODSNOW model;
- Assessment of the dynamics of changes in snow water equivalent based on future climate change scenarios.

Sources of research materials - archival and stock materials (air temperature, precipitation, height, density, moisture content of snow cover, volume of spring flood runoff) of RSE "Kazhydromet" MENR RK, Earth remote sensing data (NOAA), including Terra Climate, WEFE5 reanalysis data, also climate model data (GFDL-ESM4, IPSL-CM6A-LR, MPI-ESM1-2-HR, MRI-ESM2-0, UKESM1-0-LL) of ISIMIP phase CMIP6 projection data set.

Methodological basis of the research. The approaches used in the dissertation work are based on the application of general scientific and specialized statistical methods of research and empirical method of modeling. For comparative and descriptive analysis of changes in snow water equivalent, statistical methods, estimated by the method of least squares and nonparametric Mann-Kendall test, were applied. Cartographic methods were applied to analyze the spatial distribution of moisture reserves. The V03 module of the MODSNOW model, programmed in Fortran language and based on the empirical method (degree-day method) of modeling, was used for modeling of snow water equivalent. The accuracy of data reproduction by the model was evaluated using statistical criteria such as correlation coefficient, determination and Nash-Suttcliffe efficiency (NSE), percentage error (PBIAS), root mean square error (RMSE), normalization of root mean square error (RSR). Estimation of future changes in moisture content was made by ensemble forecasting method, which is based on ISIMIP projection data of CMIP6 phase under two climate change scenarios SSP1-2.6, SSP5-8.5. On the basis of projected data of snow cover moisture content by regression analysis method, estimation of future changes in spring flood runoff layer of Esil and Nura rivers under two climate change scenarios SSP1-2.6, SSP5-8.5 was made.

Relevance of the thesis research. The study area belongs to the territory with seasonal snow cover, which is an accumulator of precipitation in winter and a source of spring moisture reserves. Snow water equivalent provide a significant share not only of water resources in the northern and central regions of the country, but also determine spring moistening of soil in the pre-sowing period. A deficit in the amount of snow cover can lead to drought, while spring melting of the snow cover can lead to an increase in water levels, floods and emergencies.

The relevance of the research work is determined by the fact that snow cover is an important part of the climate, which from the point of view of the local issue is the main climate-forming factor affecting weather, hydrological and soil processes, and the assessment of changes in climate resources as a result of global climate change. At the same time, the main characteristics of snow cover are climate-dependent and are sensitive indicators of climate change. That is, snow cover acts both as a factor that shapes the climate and simultaneously as a climate-dependent indicator. In turn, climate change can lead to deficit and uneven distribution of water resources in Kazakhstan as a whole and in the territory of the studied basins of the Esil and Nura-Sarysu rivers in particular.

Food and water security are key aspects of sustainable development of any country in the world. The territory of Kazakhstan belonging to the sharply continental climate faces unique challenges related to food resources and water availability. The plains of our republic are the most exposed to these challenges. In such cases, it is necessary to seek solutions to minimize and avoid economic damage associated with possible multidirectional fluctuations in the volume of water resources, especially water scarcity.

In this regard, for effective management and planning of water resources in the territory of Esil and Nura-Sarysu water basins located in the central and northern regions of the republic, and for sustainable water supply to the population and

economy, as well as for taking measures for adaptation to climate change, it is necessary to study in detail the current and expected changes in snow cover moisture reserves under climate change conditions.

Scientific novelty of the study is determined by the following:

- An updated assessment of spatial and temporal changes in snow water equivalent in the territory of the Esil and Nura-Sarysu basins for 1971-2020 was carried out;
- changes in the main climate indicators (air temperature, precipitation amount) at the level of water basins for 1941-2021 were revealed, as well as their trends for 1976-2021 using modern software tools;
- the dynamics of changes in snow water equivalent for 1971-2020 period was studied;
- for the first time using the MODSNOW model, the data on snow water equivalent were simulated, and the model was calibrated and validated for 1980-2020;
- for the first time the change in snow water equivalent for the long-term period was estimated on the basis of prospective climate change.

Main provisions for defense:

- The analysis of climate change revealed statistically significant increases in seasonal and annual air temperatures in the study basins. The largest increases occur in the spring and winter seasons of the year, which influence the dates of formation and destruction of stable snow cover. A statistically significant increase in average winter precipitation on the territory of the studied basins was also revealed;
- Based on multiyear data, the norms of snow water equivalent for each station in the studied areas were determined. As a result, it was established that in the spatial distribution of snow water equivalent in the Yesilsky WHB, its maximum values are observed on the western slopes of the Kokshetau upland, in the areas of the Zhabai and Kalkutan river basins, and its minimum values - in the plain areas of North Kazakhstan and eastern part of Akmola oblasts. In the Nura-Sarysu WMB the distribution of snow cover is subject to latitudinal regularities, but on the territory of the Sarysu River formation the regularity is broken.

The trend of snow water equivalent increase in the territories of Esil and Nura-Sarysu WHBs was revealed. In Yesilsky WMB statistically significant increases in the trends of temporal changes are revealed in the western part of the territory, and in the northern part of their decrease. In the Nura-Sarysu WMB the decreasing trend is observed in the southern part of the WMB, but in the northern part of the basin a statistically significant decreasing trend is observed at the Karaganda ARD station, and in the rest of the basin a slight increase, a statistically significant increasing trend is observed in the northeastern part. These changes are also confirmed by Fisher's F-criterion calculations, as well as by the results of the non-parametric Man-Kendall test

Scientific and practical significance of the research work. The significance lies in obtaining new scientific knowledge and data on snow water equivalent in the present and future under climate change conditions.

The scientific and practical significance of the research on snow water equivalent in the territory of the Esil and Nura-Sarysu basins is related to their impact on the climate regime, water resources, as water resources of these water basins are among those that are formed only on the territory of Kazakhstan, the most developed agricultural industry, especially the grain sector, environmental sustainability and adaptation to climate change, which is important both for sustainable development of the country and for ensuring the well-being of the population.

The results of the study can be used to prepare effective measures for adaptation to climate change in order to ensure water and food security.

Personal contribution of the author. All analyzed results of the work were obtained by the co-researcher personally, which in solving the set tasks of the dissertation research consisted:

- in collection of data on snow water equivalent, snow cover height in the territory of Esil and Nura-Sarysu basins for 1971-2020;
- restoration of missing data;
- qualitative and quantitative analysis and assessment of spatial and temporal changes in snow water equivalent under the conditions of modern climate change;
- modeling under conditions of climate change in the Esil and Nura-Sarysu basins;
- estimation of future changes in snow water equivalent based on data from global ISIMIP projection models;
- preparation and publication of the obtained scientific results on the subject of the study. The main provisions of the scientific articles are reflected in the sections of the dissertation for the degree of Ph.D. degree.

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

- At the international scientific conference of students and young scientists "Farabi əlemi" in 2021;
- at the international scientific conference of students and young scientists "Farabi əlemi" in 2023.

On materials of the dissertation research 10 printed works are published, including 4 articles in the journals included in base Scopus, 3 articles in republican scientific journals from the list of Committee on control in the sphere of education and science of MES RK, 2 articles in materials of the international conferences, 1 article in scientific editions.

Structure of the dissertation. The dissertation is set out on 147 pages and consists of definitions, notations and abbreviations, introduction, 4 sections, conclusion and list of used sources of 177 names, including 103 in foreign languages; contains 20 tables, 55 figures and 3 appendices, presented on 18 pages.