Impact of Projected Climate Change on Water Quantity and Quality of the Ukrainian Rivers: Assessment and Adaptation Measures

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Abstracts

The results of implementation of the National Climate Program in the area of study of climate change impact on water quantity and water quality of Ukrainian rivers are summarized. With purpose of assess the present impact of regional climate change, the complex statistical analysis of long-term air temperature and precipitation data series, as well as river flow data series, for different hydrological periods have been used. The results of calculation for ensemble of six GAOC models have been used to project changing air temperature and precipitation in the XXI century. The assessment of possible changes in a hydrological regime and water resources under possible climate change has been carried out based on approaches, which were developed by the State Hydrological Institute (Russia). Essential peculiarities for northern and southern rivers as well as for mountain ones were revealed. The territory with increased water stress due to a climate change is expected to be more than twice larger than the territory with a decrease in water stress. The researches of a climate change impact on water quality have shown that the ecological status of the most of rivers can get worse. The obtained results allowed developing of recommendations concerning adaptation measures.

Keywords: climate changes, waters

Introduction

The IPCC released its Fourth Assessment Report, describing the likely impacts of climate change on hydrological regime and water resources. The directions of this change determine water resources availability, operating of water depending branches of industry and agriculture in many regions throughout the world, including Ukraine.

Ukraine is the second largest country in Europe with the area of 603.7 thousand km^2. The climate of Ukraine is of moderate-continental type, except for a narrow belt of the Southern coast of Crimea where it is of the subtropical type. The territory of Ukraine is located within the following natural zones: forest zone (about 20% of total territory of country), mixed forest-steppe zone (about 35%) and steppe zone (about 40%). The mountains regions are situated in the western side of the country (Ukrainian Carpathians) and in the southern side (Crimean Mountains).

Ukraine has about 22000 rivers with a total length of 170000 km. The most of rivers drain into the Black Sea and Azov Sea basins. Water resources are not equally distributed throughout Ukraine. Sufficient resources are found in the north and the north-west of the country, while the south is poorly endowed. Average annual precipitation varies from south - east to west, with 300 mm in the semi-arid south-east Black Sea and Azov coastal zones to 1500 mm in the Ukrainian Carpathians mountain region. The runoff of the Dnypro, Dniester, Siversky Donets, Western Bug, Southern Bug and Danube rivers with their tributaries, as well as of the small rivers belonging to the Black and Azov Seas basins, is the main source of surface waters in Ukraine. The average annual runoff of these rivers is shown in the Table 1.

Table 1. The average annual runoff of the main river basins of Ukraine

River basins	Average annual runoff, cub km^3		
	Total	Formed within the territory of Ukraine	Inflow from other countries
Western Bug	1.4	1.4	
Danube	133.8	10.8	123.0
Dnister	10.7	9.7	1.0
Southern Bug	3.2	3.2	
Dnypro	53.5	19.1	34.4
Siversky Donets	4.81	2.96	1.85
Black and Azov river basins	1.82	1.82	
Total	209.23	48.98	160.25

160.25 km^3 (about 76%) of surface waters come from neibouring countries - Russian Federation, Republic of Belorus, the Danube river basin countries, and only 48.98 km^3(about 24%) are formed within the territory of Ukraine. So, Ukraine can be referred to the countries with insufficient water supply (1,6 km^3 of water in a year per a inhabitant). According to this index, Ukraine occupies one of the last places in Europe.

On the other hand, river floods and related inundations are common for the majority of rivers in Ukraine. The river inundations are among the most frequent hazards in Ukraine. The spring floods are the most characteristic phase of the hydrological regime of the plain rivers. Snow-rainfall floods occur in the Carpathian mountain rivers during the winter-spring period. The rain floods are typical hydrological events for Carpathian mountain rivers from April to October.

Due to this reason, surface waters can be regarded as a restricting factor for social development in the most regions of Ukraine.

Ukraine has a large experience in the area of climate researches, including researches of impact of climate factors on hydrological regime and water resources. The State Hydrometeorological Service is the principal governmental body in Ukraine responsible for meteorological, climate and hydrological observation, hydrometeorological forecasting, providing different users with climate and climate-related services. Researches in this area have been carried out by a number scientific and educational institutions subordinated to the State Hydrometeorological Service, the National Academy of Sciences, the Ministry of Science and Education.

In Ukraine, the systematic researches of climate change, including its impact on surface waters, started in the 1990s after signing by Ukraine the United Nations Framework Convention on Climate Change in June 1992. This fact created a legal base for planning and implementation on national level the complex measures in the area of researches of impact of climate change on natural resources, environment and economy of Ukraine, and elaboration of adaptation measures. The elaboration of the National Climate Program of Ukraine was one of the first steps in the area of this activity.

The National Climate Program of Ukraine was elaborated by the State Hydrometeorological Service in co-operation with the National Academy of Sciences and others Ukrainian institutions. A number of governmental and scientific institutions were involved in the implementation of this Program. The author of this paper was nominated as the responsible person for coordination of researches in the frame of the Program section titled “Assessment of impact of climate variation and change on hydrological regime and water resources’.

The survey of results of implementation of the National Climate Program in the area of studies of climate change impacts on water quantity and water quality of Ukrainian rivers is presented in this paper.

Method and materials

In order to assess the present impact of regional climate change on hydrological regime and water resources of Ukraine, the complex statistical analysis of long-term air temperature and precipitation data series, as well as river flow data series for different hydrological periods, have been used. Data of meteorological and hydrological observation of the State Hydrometeorological Service provided a basis for these researches. Evaluation of the present climate impact on river runoff has been carried out for rivers, which are not essentially used for human activities and where a duration of observation is not less than 70 years.

The general process of evaluation of expected climate change impact on hydrological regime and water resources is presented at Figure 1.

The results of modeling of the expected climate change in the frame of implementation of CMIP3 (Coupled Model Intercomparison Project, phase 3) for three (A2, A1B and B1) IPCC (SRES) scenarios of the world’s economical and social development have been used in order to project the regional climate change in Ukraine for XXI century. The results of calculation for ensemble of six Global Atmospheric and Ocean Circulation (GAOC) models (Table. 2) have been used to project changing air temperature and precipitation in XXI century.

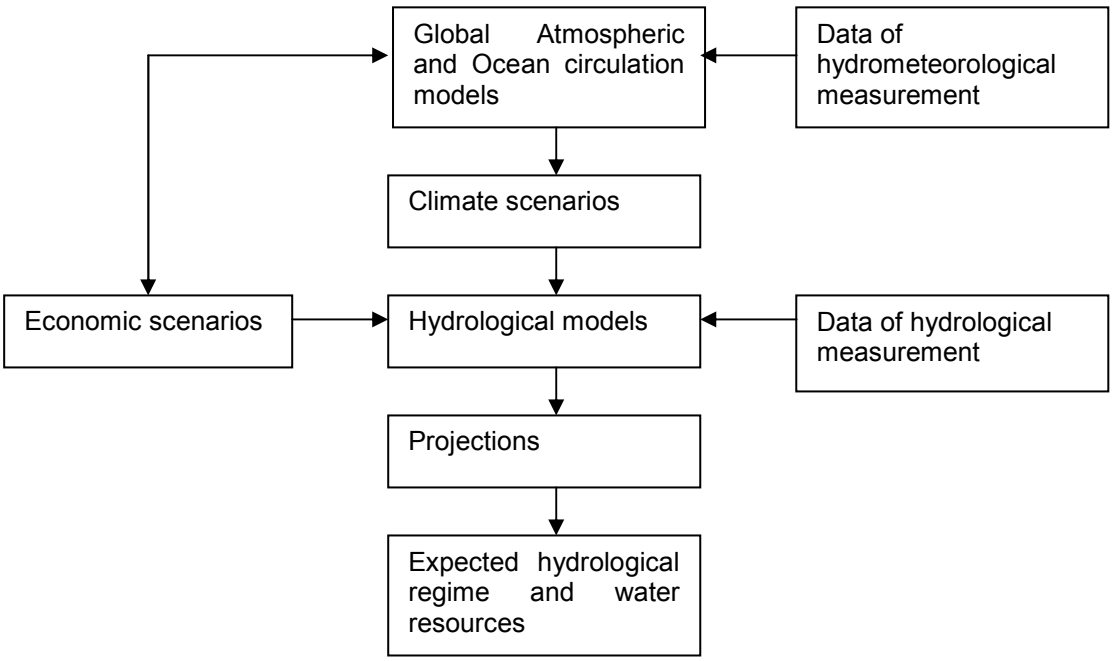


Figure 1. General process of evaluation of expected climate change impact on hydrological regime and water resources

Table 2. Global Atmospheric and Ocean Circulation models used for projecting the climate change

Model	Country	Developer	Calculations upon scenarios (A2-A1B-B1)
NCAR-CCSM3	USA	National Centre for Atmospheric Research	4-7-9
CGCM3.1 (T47)	Canada	Canadian Centre for Climate Modelling and Analysis	5-5-5
ECHAM5/MPI-OM	Germany	Max Plank Institute for Meteorology	3-4-5
GFDL	USA	Geophysical Fluid Dynamics Laboratory	2-2-2
MIROC3.2	Japan	JAMSTEC	3-3-3
UKMO-HadGEMI	UK	Met Office/Hadley Centre for Climate Prediction and Research	2-2-2

The assessment of possible changes in a hydrological regime and water resources of Ukrainian rivers under possible climate change until 2050 has been carried out by Ukrainian hydrologists based on approaches, which were developed by the State Hydrological Institute (Russia). The following methodological approaches were used:

- river basins with areas up to 15,000 – 20,000 km^2 and with minimum human impact on runoff have been included in researches;
- water balance models with ten days period time steps were used to simulate the impact of climate change on river flow;
- combination of water balance models and fluvial hydraulic methods were used to estimate an impact of projected climate change on flow of the Dnypro river – the largest Ukrainian river.

Findings and Discussion

Present climate change and its impact on surface waters

The researches have shown that the present change in temperature regime in Ukraine corresponds to the global one. But, there are some peculiarities in temperature changing in different parts of the country. The mean annual air temperature has increased up to 1°C in the northern part of Ukraine (forest natural zone), but it has not practically changed in other parts of the country located in the mix forest – steppe and steppe zones. It should be noted that an increase in the mean annual air temperature is mostly caused by warming

(up to 2°C) during winter months (December- February). Any changes in the mean annual air temperature in summer season (June – August) have not been revealed within the plain territory. Some decrease in the mean annual air temperature has been observed in the Carpathians mountains. The annual precipitation sum has also increased within the largest part of Ukraine. Generally, this growth of precipitation was caused by increased precipitation in winter and spring (March – May) seasons. There are practically no changes in precipitation in summer and autumn seasons.

The researches showed that there were no large changes in the mean annual water discharges for long-term period for rivers located in different natural zones. An essential trend of mean annual water discharges has not been revealed (Table 3).

Table 3. Regression's equations of trends of the mean annual discharges (by A. Shereshevskyi and V. Manukalo)

River – Station	Observation period	Regression's equation
Dnipro – Kyiv	1928 -2007	Y = 0.04X + 163
Desna – Chernigiv	1895 - 2007	Y = 0.02X + 328
Siversky Donets – Zmiiv	1923 - 2007	Y = -0.04X +48.3
Pivdennyi Bug – Olexandrivka	1914 - 2007	Y = 0.08X + 85.5
Prut – Chernivtsi	1895 - 2007	Y = -0.05X + 97.7
Psel – Zapsilia	1950 - 2007	Y = -0.07X +43.3
Uzh – Uzhgorod	1947 - 2007	Y = -0.04X + 30.2
Dnister – Zalischyki	1985 - 2007	Y = -0.07X +136
Latoritsa – Mukachevo	1947 - 2007	Y = -0.02X + 22.7

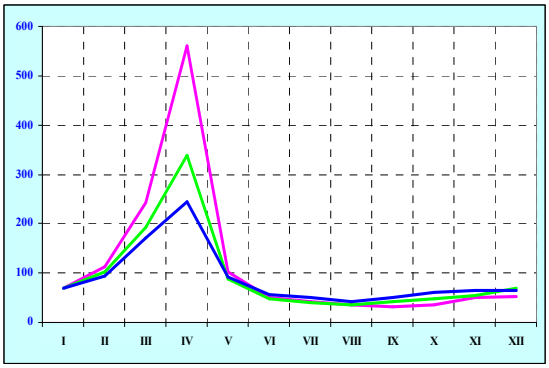
Analysis of season's river runoff changes has shown the next results (Table 4):

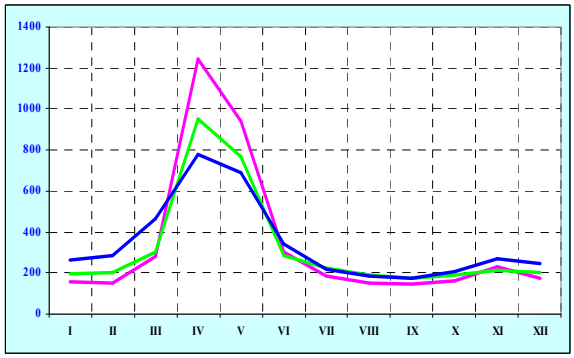
- an essential increase in water discharges for the most of rivers in winter months;
- an increase in summer flow for northern rivers;
- an essential decrease in flow for a period of snow spring flood for the most rivers. The maximum spring flow discharges became smaller approximately by 25% - 40% during a period under investigation.

Table 4. Regression's equation of trends of mean season's discharges (by A. Shereshevskyi and V. Manukalo)

River – Station	Months		
	December - February	March - June	July - November
Dnipro - Kyiv	Y = 7.28X + 460	Y = -7.33X + 213	Y = 2.17X +556
Desna – Chernigiv	Y = 1.94X + 142	Y = -1.87X + 326	Y = 1.88X +134
Siversky Donets - Zmiiv	Y = 2.73X + 324	Y = -3.82X + 112	Y = 0.91X + 97.5
Pivdennyi Bug – Olexandrivka	Y = 2.87X + 87.5	Y = -3.72X + 98.5	Y = 1.13X + 77.7
Prut – Chernivtsi	Y = 3.67X + 111	Y = -5.25X + 140	Y = 1.33X + 106
Psel – Zapsilia	Y = 2.49X + 55.7	Y = -2.85X + 78.5	Y = 1.15X + 81.1
Uzh – Uzhgorod	Y = 3.77X +28.2	Y = -3.45X + 50.0	Y = 0.42X + 33.5
Dnister – Zalischiki	Y = 3.00X +182	Y = -2.68X + 176	Y = 0.49X + 167
Latoritsa – Mukachevo	Y = 3.55X +37.9	Y = -2.93X + 61.2	Y = 0.69X + 67.0

The changes in distribution of daily discharges during a hydrological year for different Ukrainian rivers (a considerable decrease in flow in spring period and increase in flow in winter months) are presented at the Figure 2.





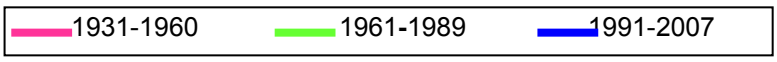


Figure 2. Mean daily discharges for different periods for Desna river (on left) and Syverskyi Donets river (on right)

The additional investigations of the impact of regional climate variability and change on the flood runoff of the Ukrainian Carpathians mountain rivers has been carried out by author for 15 rivers located within the Dnister river basin (the eastern Carpathians slope) and within the Tisza river basin (the western Carpathians slope). All series of flow discharges observations have been subdivided into 2 periods: 1948- 1979 and 1980 – 2007. The statistical analysis has shown that since 1979 an increase in mean discharges for flood periods in 13- 27% has been observed for all catchments under investigation.

An increase in precipitation, on the one hand, and an decrease in evaporation due to a decrease in air temperature for warm period, on the other hand, contributed to an increase in soil humidity. According to the observation data of the State Hydrometeorological Service network, a water supply in the soil layer of 0 – 50 cm increased by 18 – 35 mm during the last 25 years within the studied region. It faciliated a decrease in the runoff loss for infiltration in the period of floods formation. Under such conditions even relatively insignificant precipitation of warm period can cause the flood runoff formation. In general, the frequency of extreme high floods has increased for Carpathians rivers since 1979. Some of them can be regarded as natural hazards. In particular, the floods on the Dnister river in 1981, 1993, 1996, 2006, 2008, the floods on the Tisza river in 1992, 1993, 1998, 2001, 2008 caused the significant damages to the economy and population.

Expected changes in a hydrological regime and water resources

In spite of diversity of considered approaches, essential peculiarities in possible hydrological changes for northern and southern Ukrainian rivers have been revealed. The 15-20% rise in an annual runoff for northern rivers is expected. Particularly, important changes are expected in the distribution of runoff by seasons: a rise in a winter runoff and a fall in a spring runoff. Unfavorable changes are expected for southern and south-eastern rivers. The expected temperature rise and precipitation reduction (10-15%) can lead to a decrease in the mean annual runoff by 30-50%. There may be great changes in distribution of river flow during year; about 50% of annual flow will pass in winter months. An increase in a risk of droughts is projected. The region the most prone to a rise in flood frequencies is the Carpathians mountains.

Generally, the territory with increased water stress due to climate changes (southern and south-eastern parts, mountain region) is expected to be more than double than the territory with a decreased water stress. An increase in runoff in northern part of Ukraine may not lead to a beneficial increase in available water resources. A significant decrease in spring snowmelt flow is likely to reduce water availability for needs of agriculture, industry and population in summer periods.

The results of assessment of a possible runoff change for Dnipro river (main Ukrainian river) for the favorable (B1 SRES) and unfavorable (A2 SRES) climate change scenarios are presented at the Table 5.

Table 5. Assessment of a runoff change for Dnipro river at Kakhovka city (by A. Shereshevskyi, V. Manukalo and V. Osadchyi)

Probability, %	Mean annual flow, m^3/s	Mean winter flow, (December-March) m^3/s	Mean spring flow, (April-June) m^3/s	Mean summer-autumn flow, (July-November) m^3/s
Natural river flow				
5	2470	1970	5380	1780
50	1620	1076	3050	1000
95	1070	650	1680	590
B1 SRES scenario				
5	3120	5880	3000	2140
50	1700	2580	1380	900
95	730	870	680	300
A2 SRES scenario				
5	710	1030	750	580
50	230	380	300	300
95	150	160	100	160

In case of realization of B1 scenario, the Ukrainian population and economy can face a deficiency in water resources in summer-autumn periods in years with average flow and, especially, in years with low flow. Very serious water-related problems will be expected in the country every year in case of realization of A2 scenario.

The economic sectors, which could be most likely affected by impact of climate changes, include: agriculture, especially, in the southern part of territory, industry, drinking water supply, human health, human settlements, river ecosystems. The next expected economic losses in some sectors of economy could be caused by negative impact of climate change on water resources in the Dnypro river basin in accordance with A2 SRES for A2 SRES scenario: .

- hydroenergetics: a decline in production of electric power at six hydroelectric power plants will cause a need to build additional thermal power plants. It will cause additional financial expenses estimated in 250 - 350 mln. USD,
- water transport: the cost of additional works on deepening navigable river-bed for water transport is estimated about 120 - 160 mln. USD.
- Irrigation: a deficit of waters, which are necessary for irrigation, will cause a reduction of irrigable soils area. It will result in a decline in collection of grain-crops, which are among the main export items of Ukraine. The annual losses can make from 150 to 350 mln. USD.

It has to be mentioned that a problem of impact of climate change on hydrochemical regime and water quality is much less studied. Researches of this problem are facilitated by combined effects of impact of natural factors and economic activity in river catchments and beds. But, a number of significant scientific results in this area have been obtained. A redistribution of precipitation during a year, in particular, its decline in a warm period, will result in changes of hydrological and hydrochemical regimes; thus, it will influence water quality, conditions of forming of environmental flow and state of water ecosystems. First of all, it will concern changes of oxygen regime of waters, as well as natural processes, which determine contents of organic substance in waters. In combination with a large amount of pollutants, which are thrown in water objects, and irrational economic activity in catchments, the mentioned factors will intensify the negative impact on the water quality. Waters of reservoirs located on the Dnypro and Siversky Donets rivers and waters of southern rivers are the most vulnerable in the context of water quality deterioration. As a result, a general situation in the water supply, especially in regions with high density population, will be deteriorated; a degradation of small river's ecosystems is expected. An increase in frequency and intensity of river floods in Carpathian rivers in combination with a stable trend to a decrease in forest areas in this mountain region makes a threat of a radical change of conditions of forming hydrological and hydrochemical regimes. Considerable increases in sediment flow and silting of river beds are projected. These factors will cause an increase in environmental losses in this region.

Conclusions and Recommendations

The results, which have been obtained due to implementation of the National Climate Program, allowed developing of recommendations related to the necessary actions in order to mitigate the possible negative impact of climate change on waters.

It is possible to group recommendations in three large blocks:

- *legislative*: a) making amendments and changes to the environmental legislation in a part of strengthening responsibility for actions, which result in violation of natural conditions of river flow forming, b) approaching of national environmental legislation to the European one;
- *institutional:* a) improving of water management through an acceleration of implementation of principles of the Integrated Water Resources Management; b) determining national authorities, responsible for implementation of the complex approaches for solving problems of prevention negative impacts of climate changes on waters;
- *scientific and technical*: a) developing interdepartment water monitoring programs; b) improving technical base of organizations, which work in the area of water resources; c) developing interdisciplinary researches of climate changes impact on water resources and water ecosystems.

The climate change will be one of the key environmental issues over the next decades. However, there are still many uncertainties relating to the effects of climate change on surface waters. In this regard, it is very important to continue and extend scientific researchers in this area. Possible directions of these researches can include:

- development of complex monitoring of water balance parameters: river flow; evaporation from soil and water surface; water supply; water equivalent of snow pack;
- assessment of expected changes in hydrological regime and water resources using new achievements in the area of modeling climate change and hydrological processes;
- elaboration of recommendation addressed to adaptation measures.
  Presently, in order to facilitate activities on assessment of the future climate change impact on social and economic development of Ukraine, the second phase of the National Climate Program of Ukraine has been prepared by the State Hydrometeorological Service in cooperation with climate- and water depended sectors of the economy.