DOI: 10.17951/teka.2021.16.2.23-35

CLIMATE CHANGE IMPACTS ON WATER RESOURCES

Ayla Novruzova
University of Maria Curie-Skłodowska
Doctoral School of Social Sciences
ORCID ID: https://orcid.org/0000-0002-8021-9250
e-mail: aylanv94@gmail.com

Abstract: In the last few years, there has been significant interest in climate change. It has been found the direct impact on surrounding world as well as on water resources. The rise in temperature associated with climate change results in a general decrease in the proportion of precipitation falling as snow and, as a result, a decrease in the duration of snow cover in many areas. With a shift from spring snow melt to winter runoff, this has implications for the timing of streamflow in such areas. The number of people living in water-stressed countries would rise. These changes threaten the quality of drinking water, rising water levels, and drying up, which also has implications for quality of life and food production. All of the above have a devastating effect on our ecosystem. It should be noted that the impact of climate change on water resources is also the impact on the community (e.g. health security, future existence). Scientists from all across the world have already agreed that the global climate change is the result of human activity.

Keywords: climate change, water resources, climate policy

INTRODUCTION

A research problem is connected with the rise in temperature associated with climate change, leading to a general decrease in the proportion of precipitation falling as snow and, as a result, a decrease in the duration of snow cover in many areas. The number of people living in water-stressed countries would rise. These changes threaten the quality of drinking water, rising water levels, and drying up, which also has implications for the quality of life and food production.

A cognitive goal of the research is to determine the climate change impacts on water resources. Research aims are the following:

- to determine climate change as an independent variable of water resources,
- to look at the water resources as a dependent variable of climate change,

– to determine measures facing the effects of climate change on water resources.

Research assumption is that the climate change impacts on water resources. It indicates the structure of the analysis carried out in the article: climate change as an independent variable of water resources is determined; water resources as a dependent variable of climate change are overlooked; measures facing the effects of climate change on water resources are defined.

This study is based, to some extent, on the legal and regulatory frameworks for protecting the world's water resources from climate change, as well as on regional and federal programs to protect water resources from climate change currently in place in various developed and developing countries that are pursuing sustainable development goals. However, it is a completely original work, clearly focused on the protection of the world's water resources from climate change. An important feature of the study is the special attention to water problems and sustainable development in general. It is water problems, changes in the volume and regime of river flow as a result of global anthropogenic climate change that are likely to be the most serious problem in the world. The author of the study has successfully coped with the set task, analyzed all available information in detail, and presented it fully and clearly in the form of research results.

CLIMATE CHANGE AS AN INDEPENDENT VARIABLE OF WATER RESOURCES

Changes in the global climate, which have been occurring at a high (for climatology) rate over the last century and a half, have already led to significant consequences in nature. Among them there are such noticeable ones as, for example, the northward shift of the tundra and forest tundra boundaries, and, accordingly, of the forest tundra and taiga boundaries, which can be clearly detected when comparing satellite images for different periods of time. The reactions of the economy to such phenomena that have already occurred are not yet as significant as the radical structural shifts that have already begun in it in the anticipation of the upcoming climate changes in order to mitigate them – primarily the reduction of the share of hydrocarbon fuels in the energy sector and the rapid development of energy production based on its renewable sources [Aboufadel, Schlicker 1999].

Of course, the structural shifts in the global economy are not caused by the challenges of climate change alone, although they are decisive for the energy sector. But the importance of climate for civilization in general and the global economy is so great that an analysis of any aspect of global economic development reveals the important role of the climate factor. Such an analysis invariably reveals contradictions of driving forces and conflicts of interest, objective limitations (often not immediately noticed) that create the most difficult problems of development. It usually turns out that climate change is an additional factor that makes it even more difficult to solve problems that are already almost impossible to solve. This is precisely the case with the global water crisis.

Global climate change is caused by the combined effect of various causes, the main of which is an anthropogenic increases in concentrations of greenhouse gases in the atmosphere, and has several manifestations, the main one being global warming characterized by increases in global average surface temperatures. This growth inevitably leads to increased evaporation in the world oceans, which covers almost 71% of the Earth's surface, and in other surface water bodies located in areas where the climate will be warmer (these are the vast majority). The same applies to land areas [Adam, Lettenmaier 2008]. The dominant role in this process belongs to the ocean. If at present the atmosphere contains about 13,000 km^3 of water (in all three phases – gaseous, liquid and solid, in terms of the liquid phase), by 2030, with an increase of the average global surface temperature by 1.5–2°C, the increase in this volume, as expected, may be about 10–14% [Addison 2002].

However, it is not only about water vapor entering the atmosphere due to increased evaporation, but also about the fact that, when heated, the atmosphere can hold more of this gas. Therefore, it is naive to believe that precipitation will increase by exactly the same amount that evaporation will increase. The global characteristic – the amount of water in the atmosphere – is only the background against which precipitation volume is formed. Its value also depends on another global characteristic, the time of water replacement in the atmosphere, i.e. the length of time during which as much water as it contains enters the atmosphere. More precisely, these three values – global amount of precipitation (per year), time of substitution of atmospheric water and its volume – are interrelated, but the nature of the connection depends on a huge number of factors, including regional and local ones determining the movement of air masses.

This situation can be considered as a vivid example of strong interdependence of macro-characteristics of the global system and its micro-characteristics, a property that makes it extremely difficult to study, and especiallyto predict, the behavior of supercomplex systems [Allen, Ingram 2002].

RESULTS

Water resources as a dependent variable of climate change

Water is the medium through which society experiences many of the effects of the climate crisis, for example, through various risks to the energy, agriculture, health, and transport sectors. These stem from interactions with non-climatic drivers of change, such as population growth, migration, economic development, urbanization, environmental change, land use change, or natural geomorphological changes that undermine resource sustainability through reduced water supply or increased water demand. The possible model for evaluation of climate change on water resourcesis represented in Figure 1.

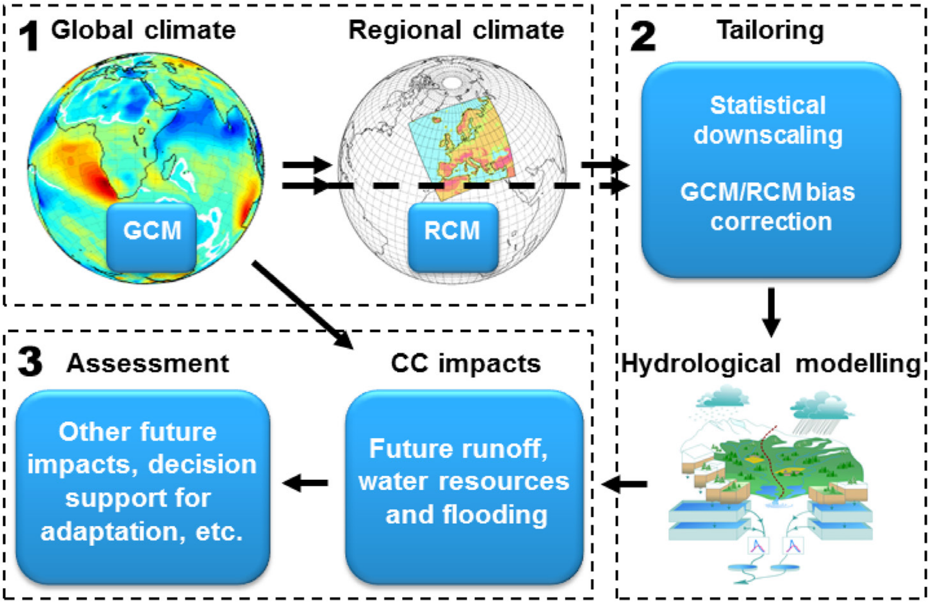

Figure 1. The model for evaluation of climate change on water resources
Source: [Salami et al. 2015].

These interactions often result in uneven and unanticipated events, such as the recent onset of drought in the Netherlands, a low-lying coastal country much more adapted to living with floods. In other cases, identifying water-related climate hotspots can be quite straightforward [Daniel, Yamamoto 1994].

Such is the case with glacial meltwater, which is a crucial source of water supply, but also a growing threat at certain times of the year to millions of people, such as those living in the high Andes in Bolivia, Peru and Chile. An estimated 3.6 billion people worldwide now live in areas with potential water shortages for at least one month a year. According to the United Nations World Water Development Report, that number will rise to 4.8–5.7 billion people by 2050, creating unprecedented competition among water users, including along political borders [Dolph, Marks 1992].

Sudden and slow-onset disasters associated with the hydrological cycle have long been a major driving force behind the forced migration of people fleeing danger. Lack of access to or supply of water – whether due to drought or a combination of drought and poor water management – is also seen as a factor influencing the decision to migrate, as it affects well-being and livelihoods. The Fifth Assessment Report of the Intergovernmental Panel on Climate Change assesses the hydrological impacts of climate change.

The 2018 Special Report on the effects of global warming of 1.5°C above pre-industrial levels outlines ways to mitigate them that are consistent with 1.5°C in the context of sustainable development. Both reports provide comprehensive information to date on the observed and projected hydrological impacts of climate change, including: limiting global warming to 1.5°C rather than 2°C above pre-industrial levels could have enormous implications for water resources, since it is possible that it would reduce the proportion of the world's population facing increased water stress caused by climate change by 50% [Newland 2005].

The impacts of land use and climate change on water resources are represented in Figure 2.

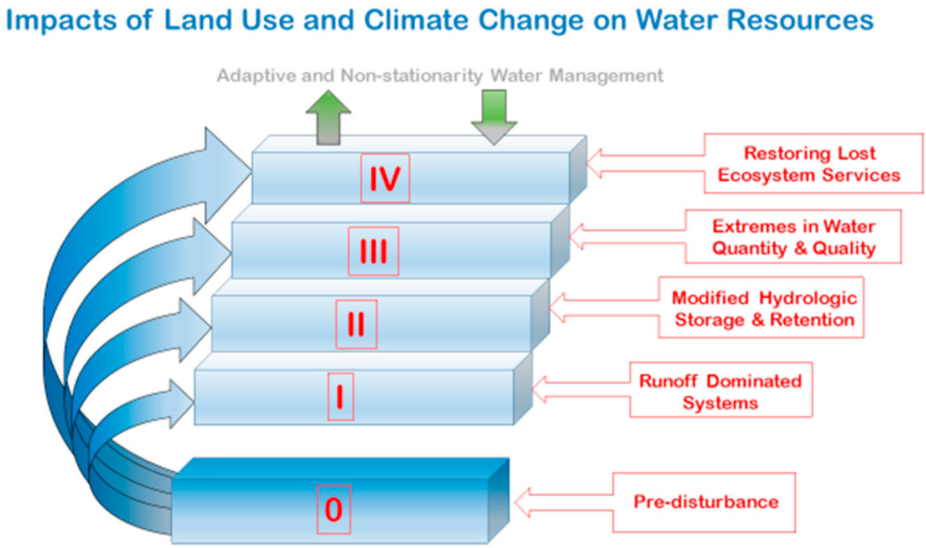

Figure 2. The impacts of land use and climate change on water resources
Source: [Salami et al. 2015].

The climate change risks associated with freshwater increase significantly with increasing concentrations of greenhouse gases. Despite the availability of current observations, and projections, many countries lack relevant data and understanding of how climate change may affect the hydrologic cycle and water-dependent services at appropriate temporal and spatial scales relevant to the decision-making process. Major gaps in observations and data include the impacts of climate change on water quality, aquatic ecosystems, and groundwater. Meanwhile, climate models continue to be refined and improved. The impact of water scarcity at GDP is represented in Figure 3.

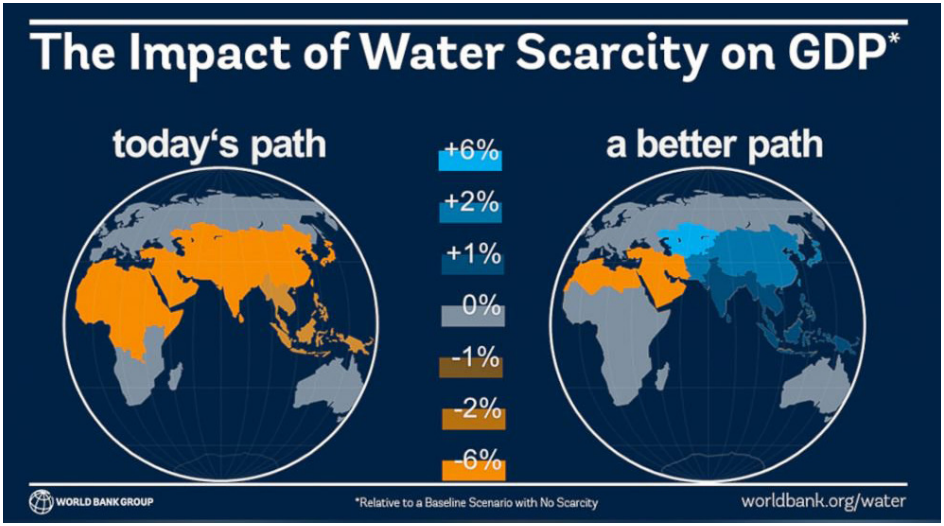

Figure 3. The impact of water scarcity on GDP
Source: [Distefano 2017].

Regional downscaling methods are now being used to obtain climate information at the smaller spatial scales needed for many climate impact studies, with added value in regions with highly variable topography and for various mid-scale phenomena. However, the quality of probabilistic precipitation predictions remains poor, especially at scales relevant to the decision-making process [Adam, Lettenmaier 2008].

The close interaction between multiple factors, combined with the inherent complexity of hydrological processes and systems, makes it difficult to accurately assess the entire cascade of changes and their causal relationships. In turn, when hydrological changes are detected, identifying their causes, one of which is climate change, is often uncertain. Nevertheless, the presence of such uncertainty does not mean that managers cannot make informed decisions. On the contrary, management options are analyzed and evaluated using risk-informed methods and approaches for a range of possible developments.

Measures facing the effects of climate change on water resources

The relationship between climate change mitigation and water is reciprocal. Measures taken to reduce emissions have a direct impact on the use and management of water resources. In turn, water extraction and management measures affect carbon emissions because of the energy intensity of water treatment and distribution systems. For example, emission reduction activities often depend on a steady supply of adequate water quality, but in assessing this factor, more than half of the companies surveyed reported that better water management leads to lower emissions [Allen, Ingram 2002].

The role that governments and other actors, including the private sector, have to play in managing water sustainably to ensure a sustainable low-carbon future is globally recognized. However, the process of awareness is not yet complete. Few institutions and actors responsible for updating and implementing national climate change strategies have fully considered water-related mitigation. Most companies are not following the lead of forward-looking corporations in how they link water, energy, biodiversity and climate goals to minimize trade-offs and maximize synergies.

Mitigation strategies. Mitigation strategies in the water context can be broadly divided into two groups: those that are nature-centered and those that rely on technology. Nature-centered solutions are a vital means of moving beyond conventional methods to address many of the world's water problems, while, at the same time, providing additional benefits that are critical to all aspects of sustainable development [Arnell 2004].

These solutions use or mimic natural processes to increase water supplies (e.g. through soil moisture retention or groundwater recharge), improve water quality (e.g. in natural and constructed wetlands), thereby reducing the risks associated with water-related disasters and climate change. In climate change mitigation approaches, ecosystems act as carbon sinks, capturing greenhouse gas emissions.

Examples include the conservation or restoration of wetlands, reforestation concerning coastal mangroves, and the preservation of natural floodplains in watercourses. Peatlands (peat soils and their surface wetlands that serve as habitat) occupy only about 3% of the world's land surface, but they contain at least twice as much carbon as all of the Earth's forests. Mangrove soils hold about 6 billion tons of carbon, yet they can absorb three to four times more carbon than their terrestrial counterparts [Mengistu et al. 2021].

These interconnected hydrological and terrestrial ecosystems represent a major untapped resource for climate change mitigation. Compared to technological solutions designed to address climate issues, nature-centered solutions often have lower costs and multiple synergistic benefits for different sectors. Currently, however, water management is still dominated by traditional, man-made infrastructure, and the enormous potential of nature-centered solutions remains underutilized [Climate Change, 2013].

Technology-based mitigation options typically involve directing investments to reduce emissions from the energy supply of water infrastructure, including drinking water, wastewater and stormwater treatment, and pumping water for agriculture and other uses. In this context, there are various water- and sanitation-related mitigation strategies that should be considered in the planning and management of water production, distribution, and treatment [Dolph, Marks, 1992]:

Improving energy efficiency. Installing energy efficient pumps and aligning them with system requirements can save 10–30% of the energy consumed during water supply and wastewater treatment.

Additional energy efficiency measures include:

- reducing non-revenue water, i.e. water lost due to leaks, metering errors, and theft,
- metering water consumption to manage water demand,
- application of water-saving technologies, especially in agriculture and industry,
- system monitoring and regulation with the prospect of automation,
- utilization of non-traditional water resources such as treated wastewater, which is regulated for irrigation [Pakmehr et al. 2021],
- production of renewable energy and its secondary use (in order to reduce the demand for fossil fuels), namely:
  a) Installation of turbines along water and wastewater systems to generate electricity (in the context of a comprehensive water management system to determine if specific developments are feasible and viable).
  b) Use of wastewater, which can be a cost-effective and sustainable source of energy, nutrients, organic particles, and other useful by-products. Biogas from wastewater treatment can be captured, thereby, contributing to making the treatment carbon-neutral. In addition, given the temperature of the wastewater, heat pumps can be installed in the sewer pipes to produce energy (Nohara et al., 2006).

Climate change mitigation measures often have additional benefits. For example, the strategies mentioned here can bring economic benefits to utilities such as Austria's Strass wastewater treatment plant, which also serves as a power plant by generating 8% excess energy, or increase the adaptive capacity of coastal communities associated with coastal mangroves (for example, by building breakwaters and providing aquatic habitat protection).

With these benefits, additional investments in energy-efficient technologies can be leveraged. In some cases, however, water-related mitigation strategies require trade-offs. For example, the impacts on water must be considered when choosing appropriate measures, especially in arid regions. For example, the production of biofuels can lead to a decrease in water reserves and an increase in water demand, as water resources are increasingly scarce in the agriculture of many countries due to their growing demand for domestic or industrial use. On-site sanitation facilities and wastewater treatment plants emit varying amounts of air pollutants (e.g. methane), so technology choices in service planning and system management can both exacerbate and mitigate climate change [Smith et al. 2004].

Hydropower reservoirs are considered major sources of low-carbon electricity that can be used to reduce emissions, but some reservoirs, such as those in tropical regions with higher concentrations of organic particles, emit GHGs due to the decomposition of organic material in the flood zone (e.g. carbon dioxide and methane). In most other cases, reservoirs act as carbon sinks, capturing more emissions than they emit. Failure to consider the role of water in all mitigation (and adaptation) activities can reduce the impact of those activities and increase the risk of maladaptation or complete failure. This is why the goal is to find the most appropriate combination of nature- and technology-oriented investments, not only to maximize benefits and maximize system efficiency, but, at the same time, to minimize costs and trade-offs [Adam, Lettenmaier 2008].

DISCUSSION

Over the past decade, floods, hurricanes, heat waves, droughts and other weather events have caused over 90% of major natural disasters. Their frequency and intensity is expected to increase due to climate change. Against this background, to eradicate all forms of poverty and hunger, combat inequality and address climate change, in 2015, countries adopted "Transforming Our World: The 2030 Agenda for Sustainable Development". The 17 Sustainable Development Goals set forth therein are interconnected and are intended to be mutually reinforcing. For example, Goal 6, "Ensure water availability and sustainability and sanitation for all", supports the other 16 Goals. Achieving Goal 6 and other water- and ecosystem-related goals is essential for public health and well-being, improving nutrition, eliminating hunger, maintaining peace and stability, conserving ecosystems and biodiversity, and ensuring energy and food security. Water is also an important component of national and local economies. Water management contributes to gender equality and social inclusion, as well as the creation and preservation of jobs in all sectors of the economy [Arnell 2003].

The Paris Agreement of the United Nations Framework Convention on Climate Change, agreed by countries in 2015, entered into force in 2016. It addresses the need to limit the rise in global average temperatures to well below 2°C above pre-industrial levels by the end of this century and to adapt to the effects of climate change. The implementation phase of the Paris Agreement focuses on Parties working to define and implement their national commitments. The Sendai Framework for Disaster Risk Reduction 2015–2030 (the Sendai Framework) was adopted at the Third United Nations World Conference on Disaster Risk Reduction in Sendai, Japan in 2015.

It includes seven goals and four priorities for action to reduce the frequency and impact of disasters caused by natural hazards. Among these priorities, the Sendai Framework calls for strengthening and implementing global mechanisms to address hydrometeorological issues in order to increase awareness and understanding of water-related disaster risks and their impact on society, and to promote risk reduction strategies. While these global agreements are separate frameworks with their own set of goals, mechanisms, and reporting requirements, their agendas overlap [Arnell 2004].

As 2030 steadily approaches, there is an urgent need for greater collaboration, coherence, and coordination among them to eliminate double or even triple repetition, incoherence, and competition for funding. Given the importance of water in achieving these goals, it can play a bridging role between these instruments, reinforcing and building on each country's commitments to climate change mitigation and adaptation, disaster risk reduction, poverty and inequality eradication, and leaving no one behind. A good example that demonstrates this linkage is Goal 13, "Take urgent action to combat climate change and its impacts".

Given that the effects of climate change are closely related to water (e.g. floods, hurricanes, and droughts), many mitigation and adaptation measures include multiple activities focused on it. Such an approach is also consistent with the Sendai Framework's goals of making new and existing water infrastructure more resilient to disasters in order to provide critical life-saving services during and after emergencies [Branstetter, Famiglietti 1999].

The Paris Agreement does not explicitly mention water. However, a closer analysis shows how much the Paris Agreement depends on adequate water resources. Many countries have identified adaptation initiatives related to freshwater, coastal water and groundwater as a top priority of their nationally determined contributions. Nevertheless, governance mechanisms and methods for harmonizing water and climate issues are still largely absent. They, together with other key national and cross-sectoral strategies such as National Adaptation Plans (NAPs), provide a strong foundation for prioritizing national priorities for appropriate climate action, with the possibility of providing guidance on priorities such as increasing water resilience to climate change, and promoting integrated resource management. They also provide a basis for investment in water and climate resilience. They also lay the groundwork for investment plans that address climate vulnerability and resilience in the broader context of the Sustainable Development Goals and the Sendai Framework [Climate Change 2013]. The latest modeling studies estimate that approximately 7% of the world's population is projected to lose at least 20% of its renewable water sources when the next phase of global warming occurs [Nohara et al. 2006].

Since the mid-twentieth century, socio-economic losses from floods have increased mainly because of their increased incidence and vulnerability to floods. Projections indicate that the frequency of floods will become increasingly variable. Flood risk is expected to increase in parts of South Asia, Southeast Asia, Northeast Asia, tropical Africa, and South America [Al-Gamal 2021].

In the coming decades, climate change is likely to increase the frequency of meteorological droughts (decreased precipitation) and agricultural droughts (decreased soil moisture) in many regions that are now arid. As a consequence, short- or fast-onset hydrological droughts (reduced surface water and groundwater) are likely to become more frequent in these regions.

Climate change is negatively affecting freshwater ecosystems by affecting streamflow and water quality, as well as posing risks to drinking water, even despite conventional treatment. Sources of these risks include rising temperatures, increased sediment loads, increased concentrations of nutrients and contaminants from heavy rains, reduced dilution rates of contaminants during droughts, and disruption of treatment plants during floods [Schar et al. 2004].

In regions with snowfall, the seasonality of runoff has changed under the influence of climate, and it is likely to continue to change. Excluding very cold regions, warming in recent decades has reduced the maximum height of spring snow cover and accelerated snowmelt, causing snow reserves for the dry summer months to diminish. Smaller floods caused by melting snow have been observed, as well as instances of increased winter flows and decreased low flows in the summer [Smith et al. 2004].

Rivers fed by glaciers continue to warm, so the total meltwater output from stored glacial ice in many regions will first increase and then decrease over the next decades. Warming is increasing, making small islands, low-lying coastal areas, and deltas increasingly at risk from sea level rise and saltwater intrusion into freshwater systems. Harnessing the potential of water for climate change mitigation and adaptation requires new ideas to address two major challenges: (1) relying on the past can no longer accurately predict the future, which calls into question confidence and creates uncertainty; (2) the work of most of the tools, infrastructure and institutions currently used to interact on water issues is designed primarily for certain and stable conditions, which makes decisions tentative. These problems can be addressed, but will require a major overhaul of the way water resources are managed in terms of approach and scale. Coordination of integrated water resources management should be pursued across traditional sectoral, political and spatial boundaries.

CONCLUSIONS

Reliability of climatological forecasts leaves much to be desired and decreases together with geographical scale of water object, which regime is studied. Changes in the global climate significantly affect the water regime; from the economic point of view, this leads to negative consequences more often than positive ones. Water availability is a critical factor for a number of regions in Russia, and in the next decade may become such for almost the whole territory of the European part of the country.

However, climate change does not create new problems in connection with water resources and their use, but only aggravates already existing ones, as a rule – long-known and long-standing ones. Impact of climate change on water resources, water management and water-intensive production requires increased attention to bottlenecks in their production systems and, in the case of housing and communal services, to social aspects of domestic water consumption, sanitary and health requirements that ensure human health.

Development of the water sector in the post-industrial epoch should be based on intensification methods; the extensive approach should be recognized as possible only when the intensification potential is exhausted. An attempt to solve water problems by focusing on the expansion of the resource base under conditions of climate change and neglecting the threats caused by them can be very costly for both the living and, all the more so, for future generations. Management decisions in this field should be based on a risk-based approach, given the considerable risks of errors and high uncertainty that characterize it.

Global nature of water resources deficit, commonness of tasks on improvement of water use management for countries with different hydrological conditions dictate necessity of international cooperation development. Meanwhile, among existing international agreements and treaties related to water relations there is no document comparable in breadth of the problem and depth of its elaboration with the Framework Convention on Climate Change, Convention on Biological Diversity, Vienna Convention for the Protection of the Ozone Layer.

Tytuł: Wpływ zmian klimatycznych na zasoby wodne

Streszczenie: W ciągu ostatnich kilku lat pojawiło się duże zainteresowanie kwestią zmian klimatycznych. Stwierdzono ich bezpośredni wpływ na otaczający świat, w tym na zasoby wodne. Wzrost temperatury związany ze zmianami klimatu powoduje ogólny spadek opadów w postaci śniegu, a w konsekwencji skrócenie czasu trwania pokrywy śnieżnej na wielu obszarach. Przejście od wiosennego topnienia śniegu do spływu zimowego ma wpływ na czas przepływu strumienia na takich obszarach. Odnotowano również, że w przyszłości wzrośnie liczba ludzi żyjących w krajach z niedoborem wody. Zmiany te zagrażają jakości wody pitnej, podnoszącemu się poziomowi wody i wysychaniu, co ma również wpływ na jakość życia i produkcję żywności. Wszystkie powyższe kwestie mają niszczycielski wpływ na nasz ekosystem. Należy zauważyć, że wpływ zmian klimatycznych na zasoby wodne oznacza także wpływ na społeczeństwa (m.in. bezpieczeństwo zdrowotne, byt w przyszłości). Naukowcy zgodnie twierdzą, że wszelkie zmiany klimatyczne są wynikiem działalności człowieka.

Słowa kluczowe: zmiany klimatyczne, zasoby wodne, polityka klimatyczna

REFERENCES

1. Aboufadel, E., Schlicker, S. 1999. *Discovering Wavelets*. John Wiley & Sons, New York–Chichester–Weinheim–Brisbane–Singapore–Toronto. DOI: https://doi.org/10.1002/9781118032909.
2. Adam, J.C., Lettenmaier, D.P. 2008. *Application of New Precipitation and Reconstructed Streamflow Products to Streamflow Trend Attribution in Northern Eurasia*. Journal of Climate, 21(8), 1807–1828.
3. Addison, P S. 2002. *The Illustrated Wavelet Transform Handbook*. Institute of Physics Publishing, Bristol–Philadelphia. DOI: https://doi.org/10.1887/0750306920.
4. Al-Gamal, S.A. 2021. *Climate Change and Integrated Water Resources Management to Prevent Water Disputes in Africa*. Water Productivity Journal, 1(2), 59–70.
5. Allen, M.R., Ingram, W.J. 2002. *Constraints on Future Changes in Climate and the Hydrologic Cycle*. Nature, 419, 224–232. DOI: https://doi.org/10.1038/nature01092.
6. Arnell, N.W. 2003. *Effects of IPCC SRES Emission Scenarios on River Runoff: A Global Perspective*. Hydrology and Earth System Sciences, 7, 619–641. DOI: https://doi.org/10.5194/hess-7-619-2003.

7. Arnell, N.W. 2004. *Climate Change and Global Water Resources: SRES Emission and Socio--Economic Scenarios*. Global Environmental Change, 14, 31–52. DOI: https://doi.org/10.1016/j.gloenvcha.2003.10.006.
8. Branstetter, M.L., Famiglietti, J.S. 1999. *Testing the Sensitivity of GCM-Simulated Runoff to Climate Model Resolution Using a Parallel River Transport Algorithm*. Proceedings of the 14th Conference on Hydrology. American Meteorological Society, Dallas, 391–392.
9. Climate Change. 2013. *The Physical Science Basis. Summary for Policymakers*. http://www.climatechange2013.org/images/report/WG1AR 5_SPM_FINAL.pdf [access: 12.04.2022].
10. Distefano, T., Kelly, S. 2017. *Are We in Deep Water? Water Scarcity and Its Limits to Economic Growth*. Ecological Economics, 142, 130–147. DOI: https://doi.org/10.1016/j.ecolecon.2017.06.019.
11. Lee T.L., Yamamoto, A. 1994. *Wavelet Analysis: Theory and Applications*. Hewlett-Packard Journal, 44–52.
12. Dolph, J. and Marks, D. 1992. *Characterizing the Distribution of Observed Precipitation and Runoff over the Continental United States*. Climate Change, 22(2), 99–119. https://doi.org/10.1007/BF00142961.
13. Mengistu, D., Bewket, W., Dosio, A., Panitz, H.J. 2021. *Climate Change Impacts on Water Resources in the Upper Blue Nile (Abay) River Basin, Ethiopia*. Journal of Hydrology, 592.
14. Newland, D.E. 2005. *An Introduction to Random Vibrations Spectral and Wavelet Analysis*. Dover Publications, Mineola.
15. Nohara, D., Kitoh, A., Hosaka, M., Oki, T. 2006. *Impact of Climate Change on River Runoff*. Journal of Hydrometeorology, 7(5), 1076–1089.
16. Pakmehr, S., Yazdanpanah, M., Baradaran, M. 2021. *Explaining Farmers' Response to Climate Change-Induced Water Stress Through Cognitive Theory of Stress: An Iranian Perspective*. Environment, Development and Sustainability, 23(4), 5776–5793.
17. Salami, A.W., Mohammed, A.A., Olukanni, D.O. 2015. *A Review of Models for Evaluation of Climate Change Impact on Water Resources*. British Journal of Applied Science & Technology, 8(3), 226–237.
18. Schar, C., Vasilina, L., Pertziger, F., Dirren, S. 2004. *Seasonal Runoff Forecasting Using Precipitation from Meteorological Data Assimilation Systems*. Journal of Hydrometeorology, 5(5), 959–973.
19. Smith, M.B., Koren, V.I., Zhang, Z., et al. 2004. *Runoff Response to Spatial Variability in Precipitation: An Analysis of Observed Data*. Journal of Hydrology, 298(1–4), 267–286.