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THE IMPACT OF CLIMATE CHANGE ON WATER RESOURCES IN THE ASPECT OF GLOBAL ECONOMY

WPŁYW ZMIAN KLIMATYCZNYCH NA ZASOBY WODNE W ASPEKCIE PROBLEMÓW GOSPODARKI ŚWIATOWEJ

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Summary: Climate change has been observed for many years, being a worlwide source of concern. Reoccuring droughts and changes in precipitation in some regions of the world prompted research into the influence of climate change on the drying up of water. The following study analyses the dependencies between climate change and the drying up of rivers. In the introduction a history of climate change is presented followed by an analysis of global water reasources: their availability, changes in precipitation and their causes and effects. The third chapter deals with the influence of the observed changes on the availability of freshwater in the world. The study ends with the conclusion that the impact of climate change on the drying up of water remains unclear, with the bigger problem being the impact of these changes on the reduction of the quality of water, a fact that may lead to many global problems.

Keywords: climate change, climate, river, water resources, global economy, warming.

Streszczenie: Zmiany klimatyczne są obserwowane od wielu lat i stanowią źródło niepokoju na całym świecie. Jednocześnie wielokrotne susze występujące w niektórych regionach świata oraz zmiany opadów spowodowały, że zaczęto badać wpływ zmian klimatycznych na wysychanie wód. Autor artykułu analizuje zależności między zmianami klimatycznymi a wysychaniem rzek. Początkowo przedstawiona jest historia zmian klimatycznych do obecnych czasów; następnie przeanalizowane są zasoby wodne na świecie – ich dostępność oraz zmiany w opadach wraz z przyczynami i skutkami. Kolejny rozdział dotyczy wpływu obserwowanych zmian klimatycznych na problem dostępności zasobów słodkiej wody na świecie. Na końcu autor dochodzi do wniosku, że wpływ zmian klimatycznych na wysychanie rzek nie jest jednoznaczny, natomiast większym problemem staje się wpływ tych zmian na obniżenie jakości wód, co może prowadzić do wielu problemów globalnych.

Słowa kluczowe: zmiany klimatyczne, klimat, rzeka, zasoby wodne, gospodarka światowa, ocieplenie.

1. Introduction

Climate change, which is observed for many years, is a source of controversy and discussion. In 1988 The Intergovernmental Panel on Climate Change (IPCC) was established to inform the world about a scientific view on the current state of knowledge in climate change and its potential environmental and socio-economic impacts [www.ipcc.ch/organization/organization.shtml (access: 04.02.2016)]. Furthermore, there is an international environmental treaty called "The United Nations Framework Convention on Climate Change" (UNFCCC) and there are organized yearly The United Nations Climate Change Conferences. One of the most important took place in Paris in 2015 [http://www.cop21.gouv.fr/comment-se-passent-les-negociations-durant-la-cop21/ (access: 04.02.2016)]. The representatives of 195 countries have signed the agreement which aims to respond to the global climate change threat [http://www.cop21.gouv.fr/195-pays-adoptent-le-premier-accord-universel-sur-le-climat/ (access: 04.02.2016)].

Climate change affects many different areas and it results in a lot of negatives consequences. One of them may be an impact on water levels on rivers. Particularly disturbing were the reports of the drying of rivers in Poland in the summer of 2015.

The article aims to identify the relationship between climate change and river drying. To achieve this, it is necessary to identify the impact of climate change on the depletion of rivers in the world and to indicate the consequences of river dryness. The paper was written using the following methodology: literature analysis, analysis of statistical data on temperature changes and river level, and intuitive method.

2. Climate change over the years

Climate is the statistics of weather condition in a given geographical region. It is formed by the geographical location of the area and its physical properties; solar radiation, water circulation and atmospheric circulation affect it. The climate is determined over long periods of time [Petrozolin-Skowrońska (ed.) 2005, pp. 375-376]. Probably global climate fluctuations have their origins in changes in the intensity of solar radiation, which in turn overlap with changes in the shape of the Earth's orbit. The combination of these phenomena gives both – natural variations in climate and extreme phenomena [Madeyska, Marks 2008, p. 3]. The latest ice age, which began about 3 million years ago, lasts today [Madeyska, Marks 2008, p. 5].

During this period there were also climatic variations:

- about 12,5-11,5 thousand years ago, during 100 years the average annual temperature in Central Europe increased by 4°C. Such rapid warming caused the melting of the ice sheets and the expansion of the vegetation. This process was more intensive than the changes observed today,
- 8,5-8 thousand years ago it was cooling and damp,

- 6-5 thousand years ago there was the Holocene optimum which was characterized by an average annual temperature of 1°C higher than currently, in the global scale,
- 15th-19th century CE is called "Little Ice Age" which was characterized by a significant decrease in temperature, especially in the temperate latitudes; it was preceded by medieval warming [Madeyska, Marks 2008, p. 7].

Climate warming is again being observed; for now, it is not known if another warmer epoch begins, or is it just an extended interglacial phase [Domański 2004, p. 73]. Research has shown that since the beginning of the 20th century, the temperature of both land and oceans has been constantly rising (Fig. 1).

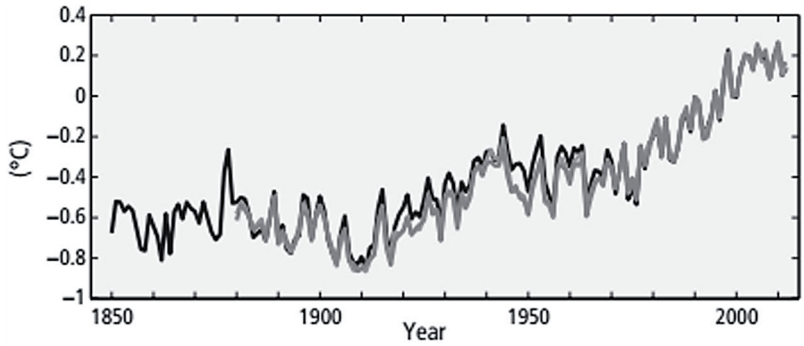

Figure 1. Globally averaged combined land and ocean surface temperature anomaly

Source: [A Report... p. 3].

Each of the last three decades was likely the warmest 30-year period of the last 1400 years in the Northern Hemisphere – the globally averaged combined land and ocean surface temperature data show a warming of 0.85°C [A Report... p. 2]. According to the Report of the IPCC, it is very likely that heat waves will occur more often and last longer, and that extreme precipitation events will become more intense and frequent in many regions over the 21st century. "It is virtually certain that there will be more frequent hot and fewer cold temperature extremes over most land areas on daily and seasonal timescales, as global mean surface temperature increases. It is very likely that heat waves will occur with a higher frequency and longer duration. Occasional cold winter extremes will continue to occur" [A Report..., p. 10].

Changes in precipitation will be different in various areas. The latitudes between 60° and 90° (N, S) the equatorial Pacific and mid-latitude wet regions are likely to experience an increase in annual mean precipitation. Meanwhile in many mid-latitude and subtropical dry regions, mean precipitation will likely decrease [A Raport... p. 11].

3. Water resources in the world

Rivers and other freshwater resources have a great impact on the functioning of man and society. The life of living organisms depends on them, so does the correct functioning of villages and towns. The least populated areas on the earth are the deserts; this is due to the limited agricultural and industrial activities and difficult living conditions. However, not only the lack of water can hinder the functioning of societies – its excess in floodplain or marshy areas also contributes to the decline of population Korenik (ed.) 2010, pp. 38-39]. Water use, in particular that for irrigation, generally increases with temperature and decreases with precipitation. However, in most countries water use has increased over recent decades, due to population and economic growth, changes in lifestyle, and expanded water supply systems, with irrigation water use being by far the most important cause [Bates et al. (eds.) 2008, p. 8]. Developing countries use water mainly for agriculture, while in highly developed countries, it is mainly used for industrial purposes [Kuciński (ed.) 2007, p. 41]. For a long time, water was considered to be completely renewable and free resource, and therefore, in places where it was abundant, water was overexploited. Only recently the policy of closed circuits (treatment of water from waste water and its use in production processes) and water thrift, especially groundwater, has begun to apply [Kuciński (ed.) 2015, p. 73].

The trouble is also the scarcity of fresh water in various parts of the world. Although 72% of the surface of the planet is covered with water, only 2.5% of this is fresh water, suitable for consumption. However, most of this water is trapped in glaciers, and some rivers and lakes flow through hard to reach areas so man uses only 0.01% of surface water resources. Most drinking water is derived from underground sources – they constitute 0.6% of the world's water resources. Still, freshwater is enough to meet the needs of people all over the world, but its uneven distribution causes many people to suffer and die from water scarcity (Fig. 2) [www.krakow.rzgw.gov.pl/index... (access 08.02.2016)].

Although many countries have access to fresh water, there is a problem of declining quality. It is the effect of growth in agricultural and industrial activities. To counter this problem, many countries (e.g., in the European Union and Canada) have established or enforced effluent water standards and have rehabilitated wastewater treatment facilities [Bates et al. (eds.) 2008, p. 9].

Another trouble of the global economy is the drought that occurs systematically in different parts of the world. Droughts can be divided into:

- climatic drought (amount of precipitation converted into available useable water, has fallen below the climatic average),
- meteorological drought (similar to climatic drought in that it focuses on precipitation, it also considers evaporation and transpiration),
- agricultural drought (the soil moisture needed to grow crops that is not secured),

- hydrological drought (expected damage due to water reduction by the depletion of water in dams, reservoirs, and rivers),
- socioeconomic drought (associated with the supply and demand of some economic goods with elements of meteorological, agricultural, and hydrological drought) [Rim 2013, p. 2799].

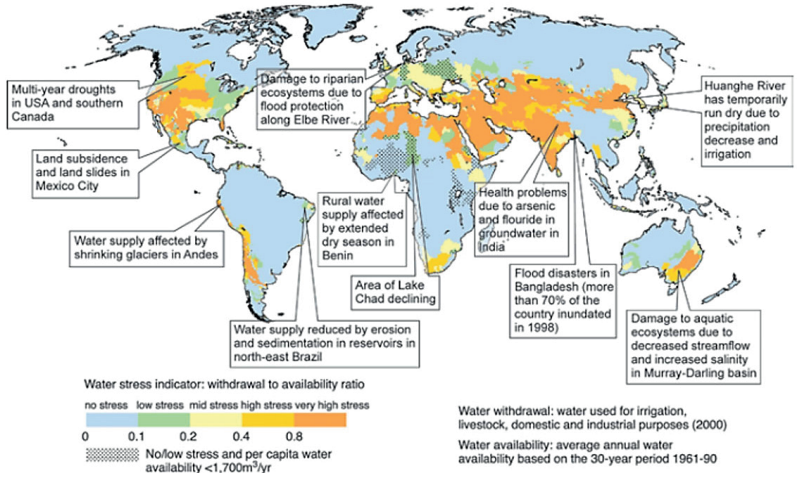

Figure 2. Examples of current vulnerabilities of freshwater resources and their management; in the background, a water stress map

Source: [Bates et al. (eds.) 2008, p. 9].

Drought is perceived as a natural disaster. Drought events are called "the creeping disaster" due to the fact they develop slower and often unnoticed and have diverse and indirect consequences. They can last for months to years, with devastating impacts on the ecological system and many economic sectors. The examples of affected sectors are drinking water supply, crop production (irrigation), waterborne transportation, electricity production (hydropower or cooling water), and recreation (water quality) [Loon 2015, p. 359]. Droughts are related to global warming, which is the cause of changes in precipitation in some parts of the world [Rim 2013, p. 2799].

4. The impact of climate change on water resources

Climate affects the amount of precipitation (see: chapter 1.). In the 20th century, precipitation over land generally increased in latitude between 30°N and 85°N, but decreased significantly, especially in the last 30-40 years, in latitude between 10°N and 30°N. These changes are shown in Fig. 3. However, it must be taken into account that climate change is not linear; one can observe decade changes: precipitation

increased markedly from 1900 to the 1950s, but declined after about 1970 [Bates et al. (eds) 2008, p. 15].

Analyzing Fig. 3A, it can be noticed that the largest decrease in precipitation was in tropical zone where for years the major problem was connected with the access to water (see: Fig. 2). However, according to Fig. 3B, there was an increase in precipitation in this area in the shorter term. In other regions of the world, the trend was likely to be over.

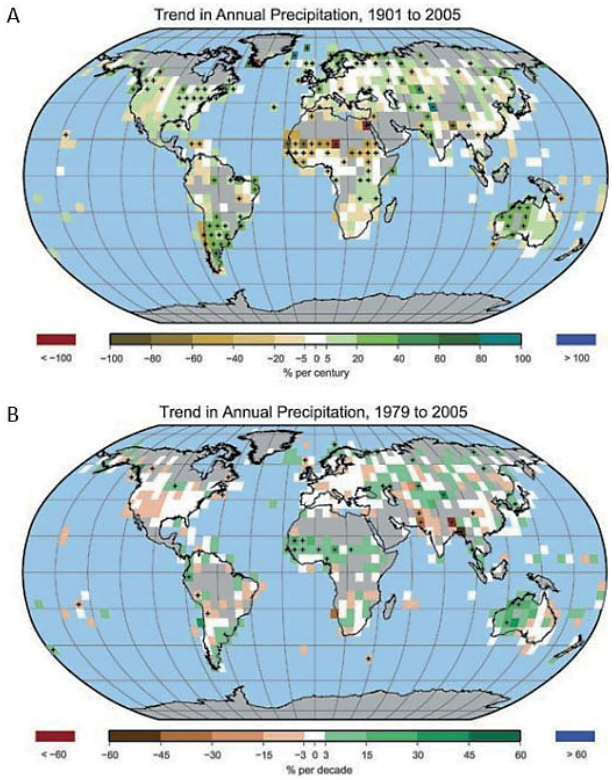

Figure 3. Trend of annual precipitation amounts, 1901–2005 (A, % per century) and 1979–2005 (B, % per decade), as a percentage of the 1961–1990 average. Grey areas have insufficient data to produce reliable trends.

Source: Bates, B.C., Z.W. Kundzewicz, S. Wu and J.P. Palutikof, Eds., *Climate Change and Water. Technical Paper of the Intergovernmental Panel on Climate Change*, IPCC Secretariat, Geneva 2008, p. 17.

A large number of studies have examined potential trends in measures of river discharge during the 20th century. The results are ambiguous – some have detected significant trends in some indicators of flow, and some have demonstrated statistically significant links with trends in temperature or precipitation. Many studies, however,

have found no such trends. Trends are not always consistent with changes in precipitation. This may be due to data limitations, the effect of human interventions such as reservoir impoundment or the competing effects of changes in precipitation and temperature [Bates et al. (eds.) 2008, pp. 21-22].

Despite in many regions, changing precipitation or melting snow and ice are altering hydrological systems, affecting water resources in terms of quantity and quality, there is no evidence that surface water and groundwater drought frequency has changed. However impacts of drought have increased mostly due to increased water demand (see: section 3.). It is also harder to eliminate the negative effects that they bring [Field et al. (eds.) 2014, p. 44].

Observed impacts attributed to climate change reported in the scientific literature; these impacts have been attributed to climate change with very low, low, medium, or high confidence, with the relative contribution of climate change (Tab. 1) [Field et al. (eds.) 2014, p. 44].

It cannot be said unequivocally that climate change has a significant direct effect on changes in water levels in rivers. However, the impact of climate change on melting glaciers is very likely and melting increases the water level (Tab. 1). Changes in water quality and quantity have been observed in almost all parts of the world. Whatever the reason, this should be taken into account when planning development strategy both internationally and nationally.

Probably, at the end of the 21st century, climate change will lead to a decline in the quality of raw water. This may also be associated with lower drinking water quality, even after standard treatment. It is caused by: increased temperature, increased sediment, nutrient, and pollutant loadings from heavy rainfall, increased concentration of pollutants during droughts and disruption of treatment facilities during floods [Field et al. (eds.) 2014, p. 66].

Due to changes in the quality and quantity of water whose causes are not yet defined, regional, national and international policies should take into account actions to counteract both droughts and floods, as well as problems related to the inability of drinking water, even after proper treatment. It should also conduct a regular study of the composition of water that goes to users.

Water quality is an important issue because it is used for drinking, domestic purposes, food production or recreational purposes. Water of poor quality can cause disease outbreaks and it can contribute to background rates of disease. World Health Organization (WHO) issued a document and conducted a strategy called "Water Quality and Health Strategy 2013-2020". Its purpose (among others) is to obtain the most rigorous and relevant evidence regarding water quality and health and facilitate the implementation of water quality and health activities through partnerships and support to Member States [Strategia... 2013, p. 1]. The United Nations (UN) has also addressed this issue observing that every year more people die from the consequence of unsafe water than from all forms of violence, including war [Ross

Table 1. The observed changes related to water resources by region

Region	Observed changes
Africa	• retreat of tropical highland glaciers in East Africa (HC, MContr), • reduced discharge in West African rivers (LC, MContr), • lake surface warming and water column stratification increases in the Great Lakes and Lake Kariba (HC, MContr), • increased soil moisture drought in the Sahel, partially wetter conditions (MC, MContr).
Europe	• retreat of Alpine, Scandinavian, and Icelandic glaciers (HC, MContr), • increase in rock slope failures in the Western Alps (MC, MinContr), • changed occurrence of extreme river discharges and flood (VLC, MContr).
Asia	• permafrost degradation in Siberia, Central Asia, and Tibetan Plateau (HC, MContr), • shrinking mountain glaciers across most of Asia (MC, MContr), • changed water availability in many Chinese rivers, beyond changes due to land use (LC, MinContr), • increased flow in several rivers due to shrinking glaciers (HC, MContr), • earlier timing of maximum spring flood in Russian rivers (MC, MContr), • reduced soil moisture in north-central and northeast China (MC, MContr), • surface water degradation in parts of Asia, beyond changes due to land use (MC, MinContr).
Australasia	• significant decline in late-season snow depth at 3 of 4 alpine sites in Australia (MC, MContr), • substantial reduction in ice and glacier ice volume in New Zealand (MC, MContr), • intensification of hydrological drought due to regional warming in southeast Australia (LC, MinContr), • reduced inflow in river systems in southwestern Australia (HC, MContr).
North America	• shrinkage of glaciers across western and northern North America (HC, MContr), • decreasing amount of water in spring snowpack in western North America (HC, MContr), • shift to earlier peak flow in snow dominated rivers in western North America (HC, MContr), • increased runoff in the midwestern and northeastern US (MC, MinContr).
Central and South America	• shrinkage of Andean glaciers (HC, MContr), • changes in extreme flows in the Amazon River (MC, MContr), • changing discharge patterns in rivers in the western Andes (MC, MContr), • increased streamflow in sub-basins of the La Plata River, beyond increase due to land-use changes (MC, MContr).
Polar Regions	• decreasing Arctic sea ice cover in summer (HC, MContr), • reduction in ice volume in Arctic glaciers (HC, MContr), • decreasing snow cover extent across the Arctic (MC, MContr), • widespread permafrost degradation, especially in the southern Arctic (HC, MContr), • ice mass loss along coastal Antarctica (MC, MContr), • increased river discharge for large circumpolar rivers (LC, MContr), • increased winter minimum river flow in most of the Arctic (MC, MContr), • increased lake water temperatures and prolonged ice-free season (MC, MContr), • disappearance of thermokarst lakes due to permafrost degradation in the low Arctic. New lakes created in the areas of formerly frozen peat (HC, MContr).
Small Islands	• increased water scarcity in Jamaica, beyond increase due to water use (VLC, MinContr)

Legend: HC – high confidence, MC – medium confidence, LC – low confidence, VLC – very low confidence (no data confirming the hypothesis), MContr – major contribution from climate change, MinContr – minor contribution from climate change

*HC, MContr should be read as: "it is highly probable that a given factor is highly dependent on climate change".

Source: based on [Field et al. (eds.) 2014, pp. 45-46].

(ed.) 2010, p. 7]. Perhaps water quality will become a bigger problem than its quantity because even if there is excess water, poor quality can contribute to increased mortality worldwide.

5. The consequences of changes in water resources in the world economy

Reducing the quantity and quality of water leads to various economic problems. First of all, less accessible sources of fresh water must be exploited through appropriating and purchasing a greater share of expensive engines, buildings, infrastructure etc. [Barbier 2004, p. 2]. The next expense is to transport water to all locations that previously had their source. The cost of water consumption is increasing, thus increasing the cost of producing most of the goods, leading to a general increase in prices and a reduction in prosperity. In addition, the efficiency of agriculture is decreasing – drought results in lower yields, and prevention leads to a significant increase in crop costs. This means that food prices are definitely overstated. The government is often helping the farmers – if there was no drought, resources would be for innovation and other investment stimulating economic development. In 2015, losses in Poland due to drought were estimated at PLN 1 billion [www.money.pl/gospodarka... (access 24.10.2017)]. The winter with the lowest amount of snowfall on record (2013-2014) and the driest summer in 40 years (2014) caused that the $20 million shortfall was paid by the government of the Canadian Northwest Territories. There in a regular year, 75% of the power is generated from hydropower so that needed to be supplemented with diesel power generation which is more expensive than hydropower generation and increases greenhouse gas emissions during combustion [www. albertawater.com/impacts-of-drought/... (access 25.10.2017)].

Low water level can cause problems with water transport, which would also affect businesses that depend on water transportation; businesses that sell boats and fishing equipment may not be able to sell some of their goods because drought has dried up lakes and other water sources. People who work in the timber industry may be affected when wildfires destroy stands of timber, which is often encountered during dry seasons [drought.unl.edu/DroughtforKids/... (access 25.10.2017)].

Climate change is also characterized by violent phenomena, such as floods (see: Tab. 1). In 2013, the flood in Canada cost about $6 billion [www.calgaryherald.com/news/Province... (access: 25.10.2017)]. The immediate impacts of flooding include loss of human life, damage to property, destruction of crops, loss of livestock, and deterioration of health conditions owing to waterborne diseases. Damage to infrastructure also causes long-term impacts, such as disruptions to supplies of clean water, wastewater treatment, electricity, transport, communication, education and health care [www.chiefscientist.qld.gov.au/publications... (access: 25.10.2017)]. A lot of people who are not protected against the effects of flooding suffer from

money losses during flood. Also, companies located in flooded areas lose their property and potential income from the period during which their activity had to be suspended [www.albertawater.com/what-are... (access 25.10.2017)].

In times of globalization, the problem does not concern one area; drought or floods in one place have effects in other countries. For example, the long-term drought in California (which began in 2012) impacted nutrition prices in Canada. In the year prior to 2015 Canadians experienced a 40% increase in the price of lettuce [www. albertawater.com/impacts-of-drought/... (access 25.10.2017)].

Research suggests that current rates of fresh water utilisation in the vast majority of countries are not yet constraining economic growth. There is probably the scope for many countries to increase fresh water use – provided it is done efficiently – and still achieve higher growth rates [Barbier 2004, p. 2]. In Australia, which has a unique problem with the amount of fresh water, restrictions have been introduced on its use – recommended time spent in the shower is 4 minutes, the car can be washed only on certain days, similarly with watering the garden [Adamiczka 2015, p. 36]. Perhaps such restrictions are not necessary, but on the basis of recent research it is known that it is important to reduce unnecessary water consumption.

6. Conclusions

Observed climate change has been affecting many processes in nature and ecosystems for many years. These changes also affect the size and amount of precipitation. Considering the fact that there are many regions in the world where there is water shortage, the further drying of rivers would lead to significant socio-economic and environmental problems, although the direct impact of climate change on river dryness has not been confirmed. If adequate preventive measures are not taken at the end of the 21st century, in many parts of the world, the quantity and quality of available water can be reduced, which can lead to global environmental, economic and social problems. At the same time, other areas may be plagued by frequent floods. Reducing water levels in many rivers in the world is alarming, including UN. Secretary-General – Kofi Annan, commented: "Water is essential for life. Yet many millions of people around the world face water shortages. Many millions of children die every year from water-borne diseases. And drought regularly afflicts some of the world's poorest countries. The world needs to respond much better" [www.unic.un.org.pl/unic-activities... (access: 10.02.2016)].

Often the problem of water quantity is raised, but the issue of the quantity of water seems to be its decreasing quality. It is caused by both climate change and human activities. The biggest international organizations (eg. the WHO or the UN) have been struggling for a few years. Nevertheless, states and cities or regions should also, in their own right, pursue appropriate policies to prevent the effects of further changes – both in terms of protection against water quality and from floods and droughts.

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