THE HYDROLOGICAL CYCLE

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Keywords: Hydrosphere, hydrological cycle, precipitation, evaporation, river runoff, surface and subsurface water, inflow, water exchange, water balance, water storage, water withdrawal, water consumption, anthropogenic climate change.

Contents

Summary

The hydrological cycle is a process of constant water exchange or water circulation in the hydrosphere, i.e. in the system of the atmosphere - Earth's surface – soil cover - upper lithosphere (to a depth of 2000 m). Water in the hydrosphere is liquid, solid or gaseous; during the hydrological cycle it moves under the effect of heat energy, gravitation and capillary forces, converting from a liquid to its solid state or gas, and back. The hydrological cycle is one of the major geophysical processes on the planet providing relative stability of natural conditions and continuous distribution of water between ocean, land and atmosphere.

Quantitative characteristics of water storage in different parts of the hydrosphere are given in this chapter, i.e. water accumulated in the oceans and seas, in aquifers, in ice and permanent snow cover, in lakes and reservoirs, in river channels, in swamps, in soils, in the atmosphere, as well as in living organisms. The general system of the global hydrological cycle is considered; it is shown that the contribution of particular type of water to the hydrosphere depends not only on its volume but also on its rate of migration or annual discharge and renewal during the water cycle. In this sense, water in river channels is advantageous if compared with the other types of water in the hydrosphere: it is renewed quickly during the water cycle (over 17 days on average), which explains the great importance of river runoff as the basic source of fresh water for different human needs.

Water exchange processes are discussed in details in the systems: ocean – atmosphere, land – atmosphere, ocean – land, surface and subsurface water. The results of this exchange are analyzed as mean annual distribution of precipitation, evaporation, river runoff and surface/subsurface runoff on the planet.

Much emphasis is focused on the problem of human impact on the hydrological cycle and on analysis of the contemporary world water balance as a quantitative characteristic of global hydrological cycle components averaged for a long-term period.

The effect of changes in the top cover of the Earth, construction and operation of reservoirs, freshwater use for human needs, anthropogenic effects on characteristics of the atmosphere due to higher evaporation because of freshwater use for human needs, and intensive burning of carbonic fuel (oil, gas, coal), are all described.

Analysis of the global water balance components has been made for a long-term period (about 50 years) for each continent, ocean and for the whole planet.

Finally, brief conclusions are made and objectives are formulated for future research, mainly related to a more accurate estimation of particular types of water storage in the hydrosphere, studies of their exchange, more detailed and reliable assessments of the components of the hydrological cycle and world water balance essential under the conditions of observed and expected great changes in the global climate.

Quantitative characteristics of the hydrosphere and the global hydrological cycle given in this chapter are mainly based on research results obtained by Russian scientists, who

traditionally generalize and analyze the data of the world hydrometeorological network and study the dynamics of global water resources and water balance.

1. Introduction: Definitions of Hydrosphere and Hydrological Cycle

There is much water on our planet in a free state, forming oceans, seas, lakes, rivers, ice cover, soil moisture and subsurface water; water is available in the atmosphere and biosphere, and it is found in minerals in the Earth's crust, bound chemically and physically.

The whole variety of water bodies and structures containing water and forming a continuous envelope around the Earth is called the hydrosphere (from the Greek words Hydor (water) and sphaira (ball)). The unity of the hydrosphere is determined not only by its continuity but by a constant water exchange among its individual parts. Unlike other natural resources, water is constantly moving in time and space, turning from a liquid phase into a solid or gaseous ones, and vice versa.

The process of constant water exchange or water circulation in the atmosphere - land surface – soil cover – upper part of lithosphere system is called the "hydrological cycle", which is one of the main hydrophysical processes on the planet. It provides a relative stability of natural conditions and characterizes a permanent distribution of water between ocean, land and atmosphere.

It should be noted that the above definition of the hydrosphere is too general and uncertain, especially if it is necessary to estimate quantitative characteristics of the hydrosphere to study the hydrological cycle.

Therefore, quite different definitions of the hydrosphere are found in scientific literature, even in the latest publications.

Late in the nineteenth century, when this term first appeared in scientific publications, it mainly included the water of oceans and seas; this definition may still be found in some modern articles. Later, the hydrosphere involved waters of land, i.e. lakes, rivers and ice cover, followed by long discussions concerning the inclusion of water of the atmosphere and biosphere, as well as the different types of subsurface water.

Even today, many specialists in applied hydrology and water management consider that the hydrosphere involves water on the Earth's surface and in its crust; this is the water of the oceans, seas and water bodies on land (rivers, lakes and subsurface water, including water accumulated in its solid phase (snow cover and glaciers). This rather extended definition (it is given in well-known glossaries for hydrology) does not include atmospheric moisture, and it does not specify *what* subsurface water should be included in the hydrosphere, i.e. in bound or free state).

This definition does not satisfy the specialists engaged in the problems of the hydrological cycle and water balance. In their opinions, the atmospheric water is an integral part of the hydrosphere. In fact, water on the Earth is available in three phases, i.e. liquid, gaseous and solid ones. If solid water is a part of the hydrosphere it is possible to include gaseous water, which is mainly found in the atmosphere, the more so that drops of water and ice particles are found in the atmosphere (see *Exchanges of Water in the Hydrosphere* and *Hydrosphere Components*).

Among scientists engaged in the global problems of the Earth's crust and subsurface water, the most popular definition of the hydrosphere is as follows: the hydrosphere involves not only water in the atmosphere but all types of subsurface water to a depth of about 300 km including water in different mountain rocks and in the chemical composition of materials.

This too extended definition of the hydrosphere that includes chemically bound water (with a great volume)—that practically does not contribute to the hydrological cycle and exceeds the water amount in the Word Ocean—is hardly reasonable, especially for studies of world water balance and determination of quantitative characteristics of different components of the hydrosphere.

Today, hydrologists, climatologists and oceanologists engaged in the problems of the global climate, ocean, water resources and water balance, use a clear and physically understandable definition of the hydrosphere: it involves all types of water on the planet in its liquid, solid and gaseous forms in the free state and contributing to the hydrological cycle. These are waters in the atmosphere, on the Earth's surface, in soil cover and in the upper layers of the lithosphere to 2000 m depth moving under the effects of heat energy, gravity and capillary forces. It also involves the water of the biosphere, mainly in plants, and contributing to the hydrological cycle by transpiration.

The author agrees with this definition of the hydrosphere, which is very important in analysis of the global hydrological cycle.

Data on water distribution over the planet and quantitative characteristics of different components of the hydrosphere are given below: the general scheme of the global hydrological cycle and the effect of different components of the hydrosphere are analyzed; water exchange processes in ocean-atmosphere, land-atmosphere and ocean-land systems are considered; surface and subsurface waters and the results of this water exchange as mean distribution of precipitation, evaporation and runoff over the planet, are considered. Particular emphasis is focused on the problem of effects of human activity on the hydrological cycle and on the analysis of contemporary world water balance as a quantitative characteristic of the global hydrological cycle averaged for particular intervals.

2. Composition of the Hydrosphere

2.1. Distribution of Water

Being one of the most widespread substances in nature, water in the hydrosphere may be found in the following three states, i.e. free liquid, solid (or ice) and gaseous (or vapor). Water forms oceans, seas, lakes and rivers; it also forms subsurface water in the upper layers of the Earth's crust and in the top soil; it makes ice and snow coverage in polar and high mountain areas. Much water is concentrated in the glaciers of Antarctica and Greenland. Some water is transported in the atmosphere as water vapor, drops of water and ice crystals, as well as in the biosphere, mainly in the plant cover where it also contributes to the hydrological cycle.

It is not easy to make a reliable assessment of water storage in the hydrosphere because water is very dynamic, it is moving constantly, turning into a solid or gaseous state from a liquid one, and vice versa. The composition of the hydrosphere is subject to changes during different life periods on Earth. Also, in quantitative assessment of water storage contributing to the hydrological cycle, it is necessary to estimate the boundaries of the hydrosphere. Studies on the quantitative assessment of the components in the hydrosphere have been made for hundreds of years. Nevertheless, recent publications during the last 20 or 30 years in many countries differ greatly; this is mainly explained by the above reasons and unfortunately by our limited knowledge of the global characteristics of the hydrosphere, pointing to the need for additional studies. Differences are particularly great in estimates of water storage in ice and snow and in subsurface water in the permafrost zone, which depends on difficult estimation by indirect methods (because of inadequate basic data).

It is very difficult to estimate the reliability of results according to quantitative indicators of the hydrosphere published by different authors.

	Area covered (km^2)	Volume (km^3)	Depth of runoff (m)	Share of world resources (%)	
				Of water resources	**Of fresh water resources**
World Ocean	361,300,000	1,338,000,000	3700	96.5	-
Subsurface water (gravitational and capillary)	134,800,000	23,400,000[1]	174	1.7	-
Predominantly fresh subsurface water	134,800,000	10,530,000	78	0.76	30.1
Soil moisture	82,000,000	16,500	0.2	0.001	0.05
Glaciers and permanent snow cover:	16,227,500	24,064,100	1 463	1.74	68.7
Antarctica	13,980,000	21,600,000	1 546	1.56	61.7
Greenland	1,802,400	2,340,000	1 298	0.17	6.68
Arctic islands	226,100	83,500	369	0.006	0.24
Mountainous areas	224,000	40,600	181	0.003	0.12
Ground ice in permafrost zone	21,000,000	300,000	14	0.022	0.86
Water resources in lakes	2,058,700	176,400	85.7	0.013	-
Fresh water	1,236,400	91,000	73.6	0.007	0.26
Salt water	822,300	85,400	103.8	0.006	-
Water in swamps	26,826,000	11,470	4.28	0.0008	0.03
Water in rivers	148,800,000	2,120	0.014	0.0002	0.006
Biological water	510,000,000	1,120	0.002	0.0001	0.003
Atmospheric water	510,000,000	12,900	0.025	0.001	0.04
Total water resources	510,000,000	1,385,984,610	2718	100	-
Fresh water resources	148,800,000	35,029,210	235	2.53	100

[1] Not taking into account subsurface water storage in Antarctica, broadly estimated at 2 million km^3 (including about 1 million km^3 of predominantly fresh water)

Table 1. Water storage in the hydrosphere of the Earth

Most scientists, however, who investigate different aspects of the hydrological cycle, often use data published by Russian scientists in 1974 in the famous fundamental monograph "World Water Balance and Water Resources of the Earth". Unlike other publications, including recent ones, that monograph contains the most complete assessments of the greatest number of components of the hydrosphere with a description of the used information, basic data and methodological approaches. Combined information from this monograph is given in Table 1.

Table 1 contains mean long-term water storage for all the components of the hydrosphere within the boundaries of the lithosphere to 2000m deep (gravitational and capillary water) and of the atmosphere up to 7 km high; moreover, 90% of the water in the atmosphere occurs within the layer from 0 to 5 km.

It should be emphasized that the above data on water storage on the Earth are quite approximate because of inadequate reliable information on individual components of the hydrosphere. The least reliable data are for subsurface water in the permafrost zone, water storage in soil and in swamps. More reliable assessments are made for the amount of water in the World Ocean, in lakes and reservoirs and in glaciers in polar and mountain areas (see *Glaciers and Their Significance for Earth Nature*).

According to the data of Table 1, the hydrosphere of the Earth involves much water, i.e. about 1386 mln.cu.km, of which 96.5% are salt water in the World Ocean. Much water is accumulated in the lithosphere (1.7% of the total storage) as gravitational and capillary water, which is estimated (as noted above) to a depth of 2000 m. About 45% of this volume is fresh water which is usually confined to a depth of 150-200 m; brackish and salt waters prevail at deeper levels.

A great amount of water is accumulated as ice in Antarctica, Greenland, islands in the Arctic and in high mountains. The total water volume there is about 24 mln.cu.km, or 1.74% of the total volume of the hydrosphere. Moreover, 90% of this amount is in Antarctica.

Subsurface ice accumulated in the permafrost zone occupies 21 mln km^2 and contains (according to approximate assessment) 300 000 cu.km (0.022% of volume of the hydrosphere). Water storages in the other components of the hydrosphere comprise very small proportions of the whole, but they are very important for the hydrological cycle because of their dynamics.

As evident from Table 1, 97.5% of the total huge amount of water of the hydrosphere is salt water, and only 2.5% are fresh waters. Out of the fresh waters, or about 35 mln cu.km, ice and permanent snow cover in Antarctica, Greenland, the Arctic and high mountain areas achieve 68.7%, and subsurface water equals 30.1% which is mainly difficult to use. Only 0.28% of the total amount of freshwater on the Earth is concentrated in lakes, reservoirs and river systems accessible for human use; this water is also very important for freshwater ecosystems (see Figure 1).

A more detailed description of individual components of the hydrosphere is shown in Table 1 and presented below.

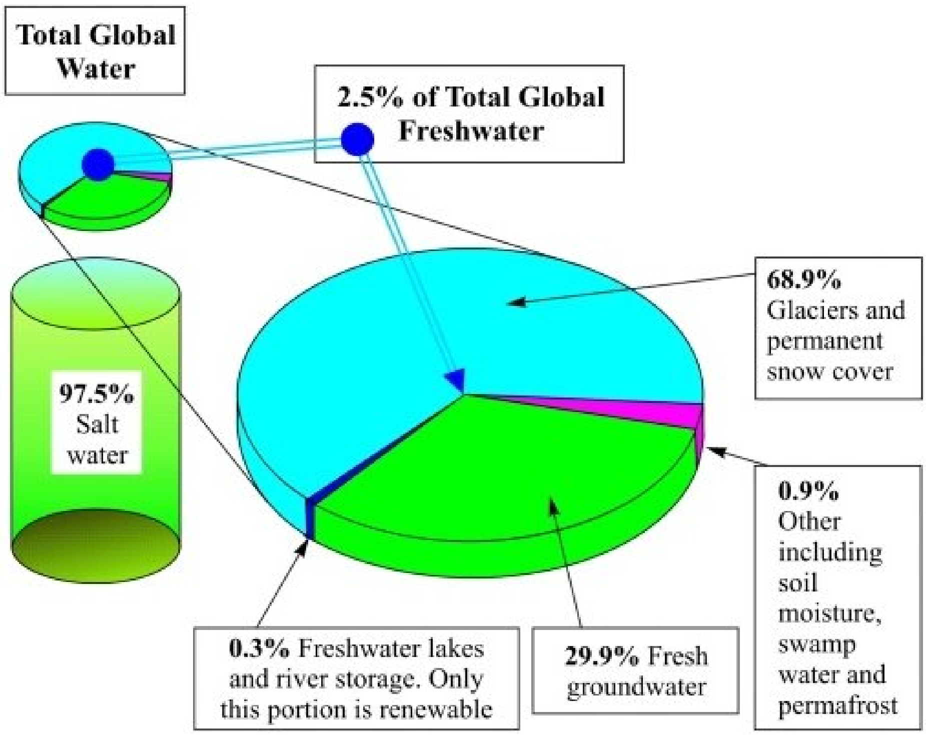

Figure 1. Distribution of water in the hydrosphere

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Biographical Sketch

Igor Alexeevich Shiklomanov was born on 28 February 1939. In 1961 he graduated from the Leningrad Hydrometeorological Institute (Hydrological Faculty). Since 1961 to the present time he has been working at the State Hydrological Institute in St. Petersburg (Russia) in different appointments. Since 1981 he has been the director of the State Hydrological Institute.

In 1967 Igor Shiklomanov defended his thesis for a candidate's degree and in 1975 a thesis for a doctor's degree on the speciality "Hydrology and Water Resources". Since 1985 he has been a professor of "Water Resources". Since 1991 he has been a Corresponding Member and, since 2000, Academician of the Russian Academy of Natural Sciences with the speciality "Hydrology".

His scientific interests include water resources, water balance, water use, the global hydrological cycle, effects of human activity and anthropogenic climate change on water resources and hydrological regime. He has published about 200 scientific papers, including 9 monographs.

He has made a notable contribution to international cooperation within the framework of UNESCO, WMO, IAHS, and IPCC. During 1992-1994 he was Chairman of the Inter-Governmental Council for the IHP (UNESCO). Since 1992 to the present he is a member of the Advisory Working Group, Commission of Hydrology WMO, and since 2000 he has been Chairman of the Working Group on Water Resources for the Commission of Hydrology (WMO).