

ANTHROPOGENIC EFFECTS ON THE HYDROLOGICAL CYCLE

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Keywords: hydrological cycle, anthropogenic factors, afforestation, land plowing, urbanization, reservoirs construction, global warming

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Summary

The scale and type of hydrological cycle changes caused by anthropogenic factors depend on the types and intensity of human impact, on physiography and on the size of the territory where these changes occur. Depending on the above, the produced changes can vary widely from local to global in scale.

For instance, forestry, urbanization, and plowing of lands on small areas and small watersheds can fundamentally change evaporation and runoff. These changes may be developed over many years in different ways, depending on physiographic features and the duration of man's impact. At the same time, the above anthropogenic factors will not be able to produce any significant effect on the global hydrological cycle, even in the remote future.

Anthropogenic factors related to direct water use for human needs, with reservoirs construction all over the Earth, are producing clear effects on evaporation and runoff

within large river basins, natural-economic regions and even countries. In Europe and Asia the annual volume of freshwater use is 15 to 16% of the total annual river runoff. In regions of water deficit there are countries where these values attain 60 to 80%. For the whole Earth, however, the total freshwater use is not great when compared with total annual river runoff—total water withdrawal is 9%, and water consumption is 5%.

The volume of freshwater use depends to a great extent on the water use technologies. There are great reserves for economic freshwater use in industries and agriculture, and their effective application may lead to a stable water use in the coming decades.

From the viewpoint of possible human impact on the hydrological cycle, the most serious problems are associated with predicted anthropogenic change in global climate due to higher concentrations of CO₂ and other greenhouse gases in the atmosphere. A rise of global air temperature by several degrees may bring about obvious changes in all hydrological cycle components in many regions of the world. This may have severe impacts on socio-economic development and the environment.

1. Introduction

Human activity inevitably affects the environment. It causes changes in plant cover and natural landscapes, and transforms water systems by making different hydraulic structures; the rate of freshwater use is very high. Great quantities of products from human activity are gradually accumulating in water bodies, in soils and on the Earth's surface—this is already an obstacle for socio-economic development in many regions and countries.

In general, anthropogenic factors cause adverse qualitative characteristics of the environment, particularly from ever-growing contamination of the air, surface and subsurface waters, soils and subsoils, and degradation of natural landscapes. These processes are well-known and have been analyzed in numerous publications. Human activity, however, can also affect the quantitative characteristics of the hydrological cycle, i. e. it can affect the regime and quantity of precipitation, evaporation and river runoff on local, regional and global scales. This problem is discussed in this chapter where different factors are considered from the viewpoint of their effects on hydrological cycle components, today and in the near future.

2. On possible change in hydrological cycle components

Human activity affects to a certain extent all basic components of the hydrological cycle: precipitation, evaporation and river runoff. Moreover, any change in any component leads to a change in the other components. It should be noted that the scale and type of change in hydrological cycle components greatly depend on the size of the area concerned. As a rule, the larger the territory the more stable the natural ratios between individual components of the hydrological cycle. Nevertheless, they are subject to the effects of anthropogenic factors.

To prove this, let us consider a scheme for the hydrological cycle (see Figure 1) with basic digital indices of its components as calculated by Russian hydrometeorologists.

According to this scheme unit equations for long-term water balance for territories of different sizes are usually presented in the following ways:

- for the Earth as a whole:

$$P = P_0 + P_{e'} + P_{e''} = E_0 + E_{e'} + E_{e''} = E \quad (1)$$

- for oceans:

$$E_0 = P_0 + R = P_0 + R_s + R_{un} \quad (2)$$

- for the areas of external runoff and river basins:

$$P_{e'} = E_{e'} + R_s + R_{un} \quad (3)$$

- for closed (endorheic) areas without outflow to the world ocean:

$$P_{e''} = E_{e''} \quad (4)$$

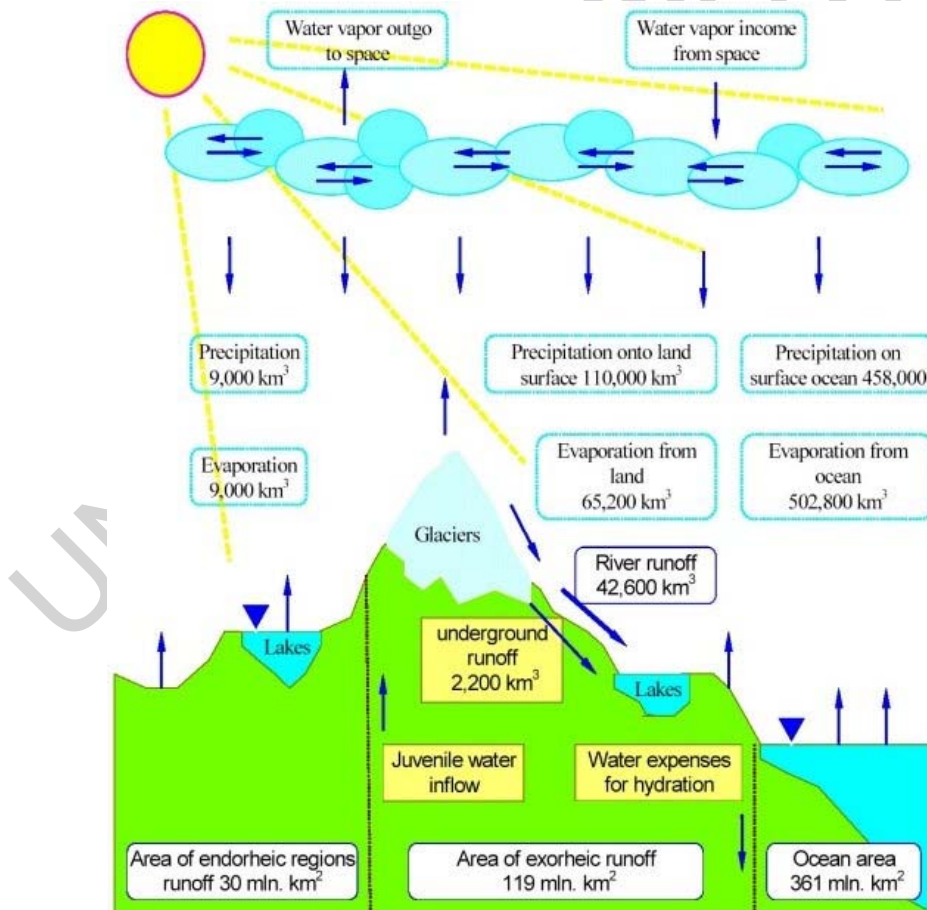


Figure 1. The global water cycle

In equations (1) to (4):

P , P_0 , P_e , and $P_{e'}$ are precipitation for the Earth as a whole, for oceans for areas of external runoff and internal runoff, respectively; E , E_0 , E_e , and $E_{e'}$ are evaporation from the Earth as a whole, from oceans, areas of external runoff and internal runoff, respectively; R , R_s and R_{un} are total runoff, surface runoff and subsurface runoff, respectively.

These equations are valid for static conditions on the assumption that water income from cosmic space is balanced by water vapor transport to cosmic space, and inflow of deep juvenile water is compensated by water losses for hydration.

To analyse the anthropogenic change in hydrological cycle components, it is very important to introduce the term “coefficient of water cycle” presented as follows:

$$K_c = \frac{P}{P_{ad}} = \frac{P_{ad} + P_e}{P_{ad}} \quad (5)$$

where: K_c is coefficient of water cycle; P is precipitation; P_{ad} is advective precipitation produced by water vapor transported from outside; P_e is local precipitation formed by evaporation from the study territory. It is evident, that the water cycle coefficient should be in good agreement with the study area: if the area is 50 000 to 1 000 000 sq. km, K_c is about 1; for areas exceeding one million sq. km K_c is larger than 1; e. g. $K_c = 1.42$ for Africa, and $K_c = 1.65$ for Eurasia.

When analysing the above equations and the approximate digital characteristics of the components shown in Figure 1, it is possible to draw some general (qualitative) conclusions on possible human impact on certain components of the hydrological cycle:

- as precipitation onto land mainly depends on water vapor fluxes transported from oceans and directly affects river runoff and evaporation from land, human activity can affect precipitation only on quite a limited scale;
- anthropogenic change in evaporation from the oceans (e.g. as a result of the ocean pollution, oil film formation on the ocean surface, etc.) can greatly affect precipitation and runoff from land;
- intensive water use for human needs in endorheic areas cannot greatly affect the total water balance and characteristics of the global water cycle;
- human impact on global climate characteristics (total precipitation, air temperature, evaporation) can greatly affect water resources of the continents, regions and river basins.

As to the anthropogenic changes in river runoff on different space scales, it is possible to note the following:

- For the whole Earth human impact on river runoff cannot change the general equation of global water balance.
- For oceans the water balances of which are slightly affected by river runoff (except the Arctic Ocean), runoff changes (even significant ones) caused by human activity cannot greatly affect their water balances.

- For assessment of anthropogenic runoff change on continents and large natural-economic regions where water cycle coefficient $K_c > 1$, it is necessary to take into account possible additional precipitation caused by increased evaporation due to human activity; this forms additional water resources, thus compensating for freshwater use to some extent.
- For individual regions and river basins with areas of 500 000 to 1 000 000 sq. km ($K_c \approx 1$) and closed water balance, increased evaporation due to human activity directly causes decreased total river runoff; meanwhile human activity contributing to redistribution of surface and subsurface components of river runoff cannot decrease the total water resources.
- For small regions and river basins where the river network does not drain subsurface water, anthropogenic change in evaporation from the basin, water diversion from the river network, and surface runoff transformation into subsurface runoff, all lead to changes in the total runoff and hydrological regime at the outlets. In such basins, human activity can lead to a complete depletion of river runoff.

3. Classification of human activity factors

There are many types of human activity, which can affect the hydrological cycle in different physiographic conditions and time-space scales, i. e. from local scales to global ones.

According to the nature and scale of human impact on hydrological cycle components (precipitation evaporation, runoff), all the factors of human activity may be combined into the following groups:

1) Factors connected with transformation of the Earth's land surface.

These are:

- forest clearance and afforestation (natural and artificial);
- land plowing, agrotechnical practices, use of meadows as pastures, etc.;
- urbanization;
- construction of reservoirs and hydromelioration practices (irrigation, drainage of swamps and waterlogged areas).

2) Factors directly connected with water diversions from the channel network (including lakes and reservoirs), the use of this water by different users and return of the used water to the water bodies.

3) Factors affecting water balance components by changing general meteorological and climatic characteristics.

These changes are caused by different processes; they vary greatly in intensity of effect and area of coverage. They include possible changes in the global climate and water cycle resulting from large scale freshwater use, and human impact on the atmosphere due to additional heat fluxes to the atmosphere, higher concentrations of CO_2 , minor

gases (freons, nitrogen oxides, methane, etc.) and atmospheric aerosols.

Within large regions and river basins of the Earth many of the above types of human activity can operate simultaneously; they are related to different groups of factors and can affect the hydrological cycle components in different ways depending on the nature of their natural variations, the scale of the effect and specific physiographic features of the study areas.

More detailed information on the effect of different anthropogenic factors on hydrological cycle components are given below for individual territories, regions and for the globe.

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Biographical Sketch

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

In 1967 he defended his theses for a candidate's degree and in 1975, a theses for a doctor's degree on the speciality "Hydrology and Water Resources". Since 1985 he has been a professor with "Water

Resources” as his speciality; since 1991 he has been a Corresponding Member and since 2000 an 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 nine monographs.

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