Hydrosphere

Book Section

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Hydrosphere

Introduction

The hydrosphere [Greek *hydor* water and *sphera* sphere] refers to the water on or surrounding the surface of the globe, as distinguished from those of the lithosphere (the solid upper crust of the earth) and the atmosphere (the air surrounding the earth). More specifically, the hydrosphere includes the region that includes all the earth's liquid water, frozen and floating ice, water in the upper layer of soil, and the small amounts of water vapour in the earth's atmosphere. The hydrosphere is the major setting for the earth's hydrologic cycle [see HYDROLOGIC CYCLE].

Origin of water on earth

The most significant feature of Earth, in contrast to our other neighbouring planets, is the presence of liquid water that covers more than two-thirds of the planet's surface.

This water came about during the early days of the formation of the Earth, when the earth's surface cooled down and the oxygen and hydroxides contained in the accreted material, diffused toward the surface. These gases then cooled and condensed to form the Earth's oceans. It is believed that since then, there has been little loss or gain in the overall quantity of the hydrosphere, despite minor fluctuations like gain from continued degassing and in falling comets; and loss at the upper layers of the atmosphere due to ultraviolet light breaking up of water molecules.

Distribution and quantity of water across the globe

The earth's water has six major reservoirs in which water resides. These include the oceans, the atmosphere (split into two reservoirs, one over the land and one over the oceans), surface water (including water in lakes, streams, and the water held in the soil), ground water (water held in the pore spaces of rocks below the surface), and snow and ice. The location of some major reservoirs on earth is shown in Figure 1.

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Figure 1. The location of some major global water reservoirs: oceans and surface water drainage basins (after Ernst, 2000)

The approximate contribution of the different components of the reservoirs to the hydrosphere, the annual recycled volumes and the average replacement periods are shown in Table 1.

Table 1. The distribution of water across the globe

Location	Volume (10^3 km^3)	% of total volume in hydrosphere	% of freshwater	Volume recycled annually (km^3)	Renewal period (years)
Ocean	1,338,000	96.5	-	505,000	2,500
Ground water (gravity and capillary)	23,400[1]	1.7		16,700	1,400
Predominantly fresh ground water	10,530	0.76	30.1		
Soil moisture	16.5	0.001	0.05	16,500	1
Glaciers and permanent snow cover	24,064	1.74	68.7		
Antarctica	21,600	1.56	61.7		
Greenland	2,340	0.17	6.68	2,477	9,700
Arctic Islands	83.5	0.006	0.24		
Mountainous regions	40.6	0.003	0.12	25	1,600
Ground ice (permafrost)	300	0.022	0.86	30	10,000
Water in lakes	176.4	0.013	-	10,376	17
Fresh	91.0	0.007	0.26		
Salt	85.4	0.006	-		
Marshes and swamps	11.5	0.0008	0.03	2294	5
River water	2.12	0.0002	0.006	43,000	16 days

Biological water	1.12	0.0001	0.003		-
Water in the atmosphere	12.9	0.001	0.04	600,000	8 days
Total volume in the hydrosphere	1,386,000	100	-		
Total Fresh water	35,029.2	2.53	100		

[1] Excluding groundwater in the Antarctic estimated at 2 million km^3, including predominantly freshwater of about 1 million km^3.
Source: Shiklomanov, forthcoming

Table 1 highlights the enormous disparity between the huge volume of saltwater and the tiny fraction of freshwater and, in addition, the long residence time of polar ice and ground water, as opposed to the brief period for which water remains in the atmosphere. Some 96.5 percent of the total volume of the world's water is estimated to exist in the oceans and only 2.5 percent as freshwater. Of this freshwater, nearly 70 percent is considered to occur in the ice sheets and glaciers in the Antarctic, Greenland and in mountainous areas, while a little less than 30 percent of it is calculated to be stored as groundwater in the world's aquifers.

Water moves through the reservoirs by a variety of processes and at different rates, with unique residence times within any reservoir. This flow of water constitutes the Earth's hydrologic cycle [see HYDROLOGIC CYCLE]. A brief summary of the major processes involved in this movement, along with the flux, *i.e.* amount of water transferred per unit time are shown in Figure 2.

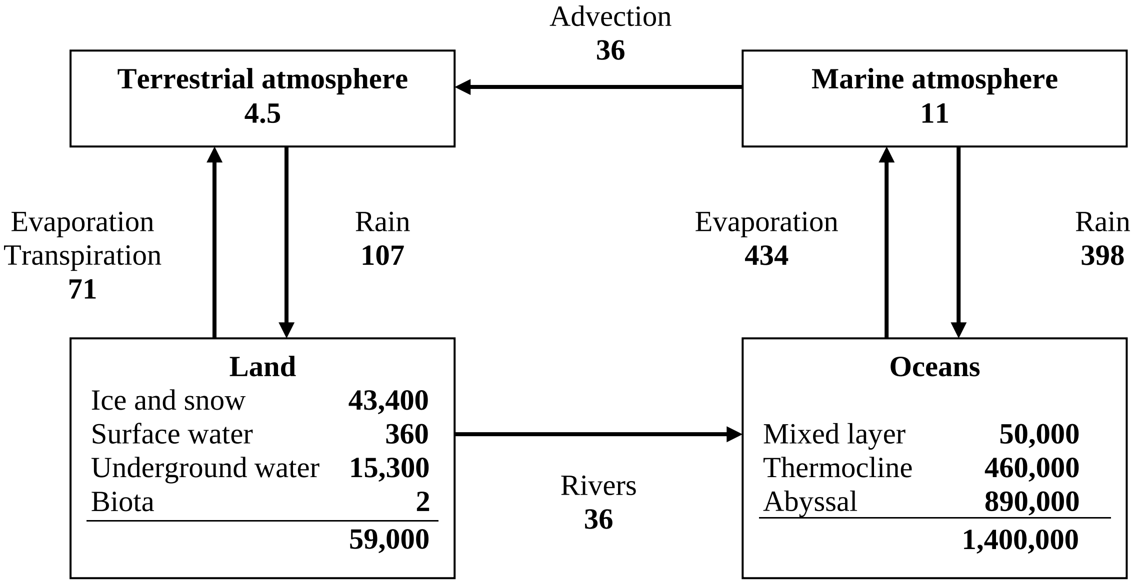

Figure 2. Estimates of global water reservoirs (in 10^{15} kg and 10^{15} kg yr^{-1}) global water cycle fluxes (After Chahine, 1992)

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The biogeochemistry of the hydrosphere

The quality of natural water in the various reservoirs of the hydrosphere depends on a number of interrelated factors. These factors include geology, climate, topography, biological processes, land use and the time the water has been in residence. Table 2 gives a comparison of major elements present in selected reservoirs.

Table 2. Chemistry of some hydrosphere components (in parts per million – ppm)

Major Element	average sea water	Average natural river water	Average rain Water
Chloride (Cl^-)	19,000	5.75	3.79
Sodium (Na^+)	10,500	5.15	1.98
Sulphate (SO_4^{2-})	2,700	8.25	0.58
Magnesium (Mg^{2+})	1,350	3.35	0.27
Calcium (Ca^{2+})	410	13.4	0.09
Potassium (K)	390	1.3	0.3
Bicarbonate (HCO_3^-)	142	52	0.12
Bromide (Br^{2+})	67	0.02	
Strontium (Sr^-)	8	0.03	
Silica (SiO_2)	6.4	10.4	-
Boron (B)	4.5	0.01	
Fluoride (F^-)	1.3	0.1	

After Ernest, 2000; and Meybeck, 1979

Rainwater has a low concentration of nutrients compared to the other reservoirs. This is because it originates as evaporated water vapour and also has a relatively short residence time in the atmosphere. Even so, it is never pure. The major constituents originate from dissolution of aerosol particles, which are formed from natural processes, like evaporation of sea spray or human activities, like burning of fossil fuels.

Naturally rain water has a slightly acid pH (about 5.5). This results from the formation of mild carbonic acid, when rainwater reacts with atmospheric carbon dioxide.

$$CO_2 + H_2O \rightarrow H_2CO_3$$

In areas, with high emission of sulphur dioxide or nitrogen oxide gases from industrial activities or fossil fuel burning, hydrolysis with rain water may result in more acidic rain and pH as low as 4. [see ACID RAIN]

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River water have an intermediate concentration of ions compared to that of rainwater and oceans. The main factor controlling the composition or river water is the weathering reaction between rainfall and rocks that this water passes through. An example is that of calcite in lime stone, which reacts with carbonic acid of rainfall, as

$$CaCO_3 + H_2CO_3 \rightarrow Ca^{+2} + 2HCO_3^-$$

Lakes also have an intermediate concentration when compared to river and sea water. Lake waters constitute a reservoir of freshwater and their composition is dependent upon four factors. These factors being, the hydrology (e.g. relative importance of groundwater or surface water inputs, evaporation); surrounding geology (e.g. carbonate rocks or granite), temperature-driven circulation patterns, and anthropogenic factors (e.g. acid rain, agricultural fertilizers). In some instances, evaporation of water from lakes formed in closed basins may result in high concentration of salts, as opposed to areas with high rainfall.

Sea and ocean waters are dominated by sodium and chlorine, followed by sulphate and magnesium. Surface sea water is alkaline, with an average pH of about 8. Sea water tends to have a more or less uniform composition in the major elements. But concentrations of minor constituents, including trace and heavy meals and nutrients vary with depth and location, resulting in marked differences in biological productivity. Organisms living on the surface of the sea water are also involved in changes in the composition of sea water, via removal of nutrients and breakdown of organic matter at different depths.

Ground water composition is a result of the rock type it is confined in (e.g. limy is to calcium as argillaceous is to silica); and chemical processes of dissolution, hydrolysis, oxidation reduction and biological processes. Moreover, anthropogenic contaminants like excess fertilizers and heavy metals may also affect the composition of ground water.

Ice consists a pure solid and has thus only few impurities in its structure. But particulate matter and gases may be trapped within it. Analysis of successively trapped gases or other anthropogenic substances like carbon dioxide in polar ice caps, has been used to study consecutive changes in atmospheric composition of the past times.

Effect of human beings on the hydrosphere

Over the last 200 or so years, sharp rise in population, urbanization, industrial development and intensification of agricultural practices have combined to largely affect most natural water bodies of the earth. This is due to the transport of the waste products from those activities by surface water, groundwater and the atmosphere. The scale and intensity of this pollution varies considerably, e.g. there are global problems such as presence of heavy metals; regional problems like acid rain; and much more localized ones like groundwater contamination.

Overall, globally, organic material from domestic sewage, municipal waste and agro-industrial effluent is the most widespread pollutant. The sewage contains pathogens which lead to disease and mortality among the populations using this water.

Moreover, this organic material has also high concentrations of nutrients, particularly nitrogen and phosphorus, which cause eutrophication (i.e. nutrient enrichment) of lakes and reservoirs. This eutrophication results in promotion of abnormal plant growth and oxygen depletion, which destroys aquatic ecosystems. Excess fertilizers, from agricultural production areas also have similar consequences.

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Acidification of surface waters as a result of acid rain has adverse effects on aquatic life and also human health.

Salinization i.e. the high concentration of salts in the soils of irrigated areas, as a result of poor drainage and high evaporative loss is also a cause of water pollution.

Sediments in the form of suspended load may affect physical structures for e.g. silting up of dams and damage to aquatic life.

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Table 3, shows a summary of the above problems by the type of water bodies polluted and the extent and reach of the effects.

Table 3. The world's major water quality issues

Issue Scale	Water bodies polluted	Sector affected	Time lag between cause and effect	Effects extent
Organic pollution	Rivers++ Lakes + Groundwater +	Aquatic environment	< 1 year	Local to district
Pathogens	Rivers ++ Lakes + Groundwater +	Health ++	< 1 year	Local
Salinization	Groundwater ++ Rivers +	Most uses Aquatic environment Health	1 - 10 years	District to region
Nitrate	Rivers + Lakes + Groundwater ++	Health	> 10 years	District to region
Heavy metals	All bodies	Health Aquatic environment Ocean fluxes	< 1 to > 10 years	Local to global
Organics	All bodies	Health Aquatic environment Ocean fluxes	1 - 10 years	Local to global
Acidification	Rivers ++ Lakes ++ Groundwater +	health Aquatic environment	> 10 years	District to region
Eutrophication	Lakes ++ Rivers +	Aquatic environment Most uses Ocean fluxes	> 10 years	Local
Sediment load (increase and decrease)	Rivers + Lakes	Aquatic environment Most uses Ocean fluxes	1 – 10 years	Regional
Diversion, dams	Rivers + Lakes + Groundwater ++	Aquatic environment Most uses	1 – 10 years	District to region

+ serious on global scale
++ very serious issue on global scale
WHO/UNEP, 1991

In general, it may be noted that the effect of pollution can reach far beyond the vicinities of its origin. Moreover, the effects may not be noticed until a substantial time has elapsed and it is too late. This calls for constant monitoring and control strategies to save the earth's most precious resource: water.

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