ENVIRONMENT – WATER INTERACTIONS

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Keywords: hydrology, limnology, hydrological cycle, ecosystem, groundwater, surface water, hydrosphere, rivers, lakes, wetlands, climate change, greenhouse effect, acid rain, eutrophication, water scarcity, water quality, pollution, sewage, sanitation, sustainable development, integrated management.

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Summary

Water is essential to life and a shortage of clean water is one of the most pressing problems facing humanity. The world's water supply is found in the five parts of the hydrological cycle. A large part (97.5%) is found in the oceans. Some water (*ca*. 2.0%) is contained in the solid state as ice and snow in snow packs, glaciers, and the polar ice caps. Another fraction is present as water vapor in the atmosphere (clouds).

Groundwater is located in aquifers underground, while fresh surface water is found in lakes, rivers, streams, and reservoirs.

Strong environmental interactions occur among water, air, soil, and living systems – the hydrosphere, atmosphere, lithosphere (geosphere), and biosphere, respectively. The physical condition of a body of water strongly influences the chemical and biological processes that occur in water.

The state of the environment is of great concern to the population, as it affects health, personal wellness, socio-economic living conditions, technology and trade. In many areas, groundwater is over exploited and its quality under threat. Eutrophication of rivers and lakes is widespread and acidification is a severe problem in some countries.

Improperly discarded hazardous wastes, losses or destruction of captation areas, inappropriate location of industries, deforestation, agricultural migration and inappropriate agrarian practices have perturbed aquatic ecosystems, influencing water quality.

Climate change has implications for both water supply and sewage systems. Greenhouse gases promote global warming, which will make water problems more critical in the next century. Natural disasters are apparently becoming more severe and more frequent.

Suitable water management can solve many of the problems of pollution and scarcity, but it cannot be handled in isolation since it is inextricably linked with land and atmospheric issues.

People's participation is becoming a central issue of our time. Improvements in understanding and use of science, technology and local and traditional knowledge will be instrumental in changing the way the water resource management is carried out.

1. Introduction

Fresh water resources are an essential component of the Earth hydrosphere and of all ecosystems. A shortage of clean water is one of the most pressing problems facing humanity.

Global freshwater consumption rose sixfold between 1900 and 1995 – at more than twice the rate of population growth. About one-third of the world's population already lives in countries with moderate to high water stress – that is, where water consumption is more than 10 per cent of the renewable freshwater supply.

About 20 percent of the world's population lacks access to drinking water and about 50 percent lacks safe sanitation. This situation is set to worsen dramatically.

If present consumption patterns continue, two out of every three persons on Earth will live in water-stressed conditions by the year 2025. The declining state of the world's freshwater resources, in terms of quantity and quality, may prove to be the dominant issue on the environment and development agenda of the coming century.

Part of the global water problem is increased usage of water for domestic, industrial and agricultural purposes. Agriculture alone accounts for 70 percent of water usage, mainly for crop irrigation. As the word's population grows, so irrigated land is expected to become increasingly significant in feeding people.

Household demand, particularly in urban areas, is rising rapidly, particularly among wealthy consumers, in developed and developing countries, with an abundance of household appliances and garden irrigation. Europe and North America are the only regions currently using more water in industry than in agriculture. On current trends, industrial water use will more than double by the year 2025 with a four-fold increase in pollutant emissions to watercourses.

Contamination of drinking water is mostly felt in megacities, while nitrate pollution and increasing loads of heavy metals affect water quality nearly everywhere. Freshwater resources cannot be increased; more and more people depend on this fixed amount; and more and more of it is polluted. Water security, like food security, will become a major national and regional priority in many areas of the world in the decades to come. The global human ecosystem is threatened by grave imbalances in productivity and in the distribution of goods and services. A significant proportion of humanity still lives in dire poverty, and projected trends are for an increasing divergence between those that benefit from economic and technological development, and those that do not. This unsustainable progression of extremes of wealth and poverty threatens the stability of the whole human system, and with it the global environment.

Unhygienic conditions and the lack of sanitation and water services cause three million children to die each year from water-related diseases. More than a quarter of the developing world's people live in poverty, of which the lack of a healthy living environment is a major component. The global community has made advances in other fields but it has failed to ensure these most basic needs of marginalised people.

1.1 The properties of water

Water has a number of unique properties that are essential to life, many of which are due to water's ability to form hydrogen bonds. Being an excellent solvent for many materials, it is the basic transport media for nutrients and waste products in life processes. The extremely high dielectric constant of water relative to other liquids has a profound effect upon its solvent properties, in that most ionic materials are dissociated in water. With the exception of liquid ammonia, water has the highest heat capacity of any liquid or solid. Because of this high heat capacity, a relatively large amount of heat is required to change appreciably the temperature of a mass of water, hence, a body of water can have a stabilizing effect upon the temperature of nearby geographic regions. In addition, this property prevents sudden large changes of temperature in large bodies of water and thereby protects aquatic organisms from the shock of abrupt temperature variations. The extremely high heat of vaporization of water, 585 cal /g at 20º C, likewise stabilizes the temperature of bodies of water and the surrounding geographic regions. It also influences the transfer of heat and water vapor between bodies of water and the atmosphere. Water has its maximum density at 4ºC, a temperature above its freezing point. The fortunate consequence of this fact is that ice floats, so that few large bodies of water ever freeze solid. Furthermore, the pattern of vertical circulation of water in lakes, a determining factor in their chemistry and biology, is governed largely by the unique temperature-density relationship of water.

Water: a unique substance
Excellent solvent ⇒ transport of nutrients and waste products, making biological processes possible in aqueous medium.

Highest dielectric constant in solution ⇒ High solubility of ionic substances and their ionization in solution.
Higher surface tension than any other liquid ⇒ Controlling factor in physiology, governs drop and surface phenomena.
Transparent to visible and longer-wavelength fraction of ultraviolet light ⇒ Colorless, allowing light required for photosynthesis to reach considerable depths in bodies of water.
Maximum density as a liquid at 4ºC ⇒ Ice floats, vertical circulation restricted in stratified bodies of water.
Higher heat of evaporation than any other material ⇒ Determines transfer of heat and water molecules between the atmosphere and bodies of water.
Higher latent heat of fusion than any other liquid except ammonia ⇒ Temperature stabilized at the freezing point of water.
Higher heat capacity than any other liquid except ammonia ⇒ Stabilization of temperatures of organisms and geographical regions.

The study of water is known as hydrology, and is divided into a number of subcategories. Limnology is the branch of the science dealing with the characteristics of fresh water, including biological properties as well as chemical and physical properties. Oceanography is the science of the ocean and its physical and chemical characteristics.

1.2 The movements of water

The most obvious characteristic of water is that it is liquid. Being liquid, it can move. The movements of the water affect both the surface structure of the land (its topography), the overall climate, and the day-to-day weather. As the lives of plants and animals are clearly influenced profoundly by topography, climate, and weather, the movements of water are clearly of profound ecological significance. The waters of the world's oceans are tugged outwards by the gravitational pull of the moon: a hill of water forms in the middle of the ocean when the moon is appropriately positioned above it. As the moon passes, the waters relax and spread. Hence the tides. The orbit of the moon is such that its gravitational pull is great one week, and smaller the next, then great again. The gyration of the Earth on its own axis tends to cause the oceans to spin.

Heat from the sun also causes the waters of the world to move. This heating is uneven: more by day that at night, and more at the equator than at the poles. In addition, the oceans are in contact with the land. The rocks of the land have a smaller specific heat than water does, which means that any given amount of heat that falls upon them will raise their temperature more than that of water. So land tends to be hotter than the surrounding sea by day, and cooler by night, and in general, hotter in summer and cooler in winter. Heat flows from regions of high temperature to regions of low temperature, so that heat is either flowing from the continents to the oceans , or from the oceans into the continents. Water that is above 4ºC expands as it is warmed, so its density is reduced and tends to float upon water that is denser. Thus, as oceans are unevenly heated and cooled, water tends to shift. These movements are superimposed on movements caused for other reasons (such as moon's gravity).
Each year from the surface of the oceans alone, 300000 cubic kilometers of water are lifted into the atmosphere by evaporation. Most of it falls back into the sea, as rain or

snow, but 100000 cubic kilometers of it falls on land. There it percolates down through the rocks into aquifers (underground water reserves), or flows as surface rivers back into the sea. This mass movement of water, ultimately powered by the Sun is known as the **hydrological cycle**.

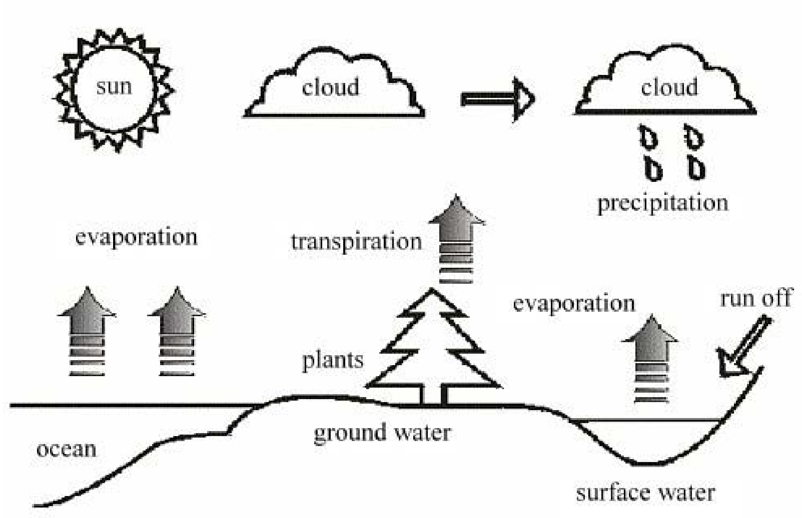

Figure 1: The hydrological cycle

The world's waters differ greatly in the amount of salts dissolved in them. Oceans have been picking up soluble materials, notably sodium chloride from the land, for millions of years. Water that has evaporated and condensed in the upper atmosphere, and the falls as rain, should be pure, except for a little carbon dioxide picked up on the way down (although, in fact, these days, it tends to contain a whole catalogue of pollutants). Water that is salty is denser than water that is fresh. So as the less salty water comes into contact with more salty water, the two water masses shift (the fresher mass tending to float on the saltier mass). Oceans account for *ca*. 97.5percent of the world water. Only 2.5 percent is fresh water. Glaciars, snow and ice polar casks account for almost 80 percent of the fresh water, groundwater for 19 percent and readily accessible surface water for only 1 percent. This low quantity of readily accessible surface water is mainly in lakes (52 percent), and wetlands (38 percent).

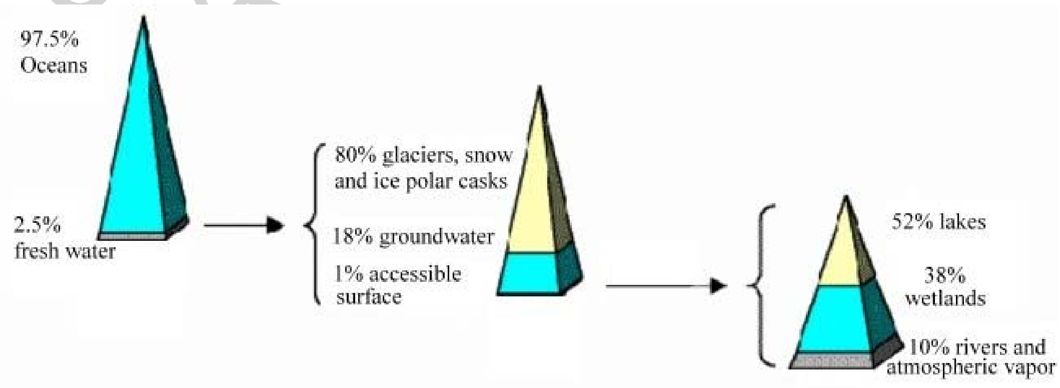

Figure 2: Water in nature

The importance of groundwater:

- ✓ represents the majority of planet's freshwater resources
- ✓ supplies at least 1,500 million urban dwellers with water
- ✓ extensive use for low-cost rural water-supply
- ✓ increasingly developed for both large and small-scale irrigation
- ✓ generally reliable in drought because of large storage
- ✓ cheap to develop because of widespread occurrence and naturally good quality
- ✓ strategic reserve protected against catastrophic events

2. Water as a Function of Ecosystem Character

Understanding of the structure and function of the world's ecosystems changed considerably during recent years as additional dimensions were progressively taken into account. Modern theories have demonstrated the nonlinear nature of biotic and abiotic processes and stressed the need for multiscale (space and time) studies. The view of the factors controlling the structure and operation of aquatic ecosystems has expanded and gradually evolved from a unifactor to a multifactor orientation. Moreover, the scale on which a process is examined may influence perception of controlling factors. This leads to a variety of problems associated with sampling, data acquisition, experimental design, extrapolation of results, and especially, consideration of ecosystem structure and function. However, all ecosystems are fundamentally defined by the way the organic matter and biogenic elements are organized in time and space with respect to environmental variability.

Strong environmental interactions occur among water, air, soil, and living systems – the hydrosphere, atmosphere, lithosphere (geosphere), and biosphere, respectively.

The hydrosphere refers to water in its many forms: oceans, lakes, streams, reservoirs, snowpack, glaciers, the polar ice caps, and groundwater.

The physical condition of a body of water strongly influences the chemical and biological processes that occur in water.

The chemical species found in water are strongly influenced by the environment in which the water is found, as well as the chemical reactions that occur.
Microorganisms play an essential role in determining the chemical composition of water.

Groundwater and surface water have appreciably different characteristics. Many substances either dissolve in surface water or become suspended in it on its way to the ocean. Surface water in a lake or reservoir that contains the mineral nutrients essential for algal growth may support a heavy growth of algae. Surface water with a high level of biodegradable organic material, used as food by bacteria, normally contains a large population of bacteria. All these factors have a profound effect upon the quality of surface water.

Groundwater may dissolve minerals from the formations through which it passes. Most microorganisms originally present in groundwater are gradually filtered out as it seeps through mineral formations. Occasionally the content of undesirable salt may become excessively high in groundwater, although it is generally superior to surface water as a domestic water source.

When we consider the Earth hydrosphere, we are always impressed by the extent of oceanic waters, which dominate the surface of the Earth. However, most of all fresh water is subsurface. Complex linkages between surface water and groundwater are determined by geologic and climatic conditions existing in drainage basins, and organisms traverse this geohydraulic continuum in association with fluxes of energy and matter. This is the essence of groundwater ecology.

Much of the world's human population depends on subsurface sources of uncontaminated water. Indeed, about 75 percent of the inhabitants of the European Community are supplied with groundwater, and in the United States 50 percent (more than 90 percent in rural areas) of the potable resource is groundwater.

Sustainability of subsurface sources:

- ✓ evaluate groundwater resources
- ✓ define optimal exploitation strategies taking account of potential side-effects
- ✓ diagnose vulnerability to quality deterioration
- ✓ design appropriate monitoring networks
- ✓ provide information in the form of groundwater resource and vulnerability maps, codes of practice and land-use planning guidance
- ✓ expert advice to encourage best practice resource management

Ecological descriptions of the underground environment were initially developed with reference to surface systems.

The primary characteristic of the physical environment is the permanent darkness, while in the surface system there is light with alternance day/night. Regarding the habitat, the underground system has restricted variety in comparison with the high diversity of the surface system. In the latter, fluctuations are frequent and with large variations and low predictability. At the macroscale, the hydrologic and geomorphologic processes of the catchments determine aquifer properties, the distribution of voids, and the water circulation characteristics. The surface environment, represented by lands (with various vegetation types), rivers, and lakes, also exerts a primary control over the underground circulation of matter and energy. Aquifers receive from the surface, climatic pulses and organic matter that are essential elements for their life and evolution.

The mesoscale domain encompasses processes expressed as hydrodynamic controls, matter and energy fluxes, and the human impact. Aquifers are influenced to a greater or lesser extent by different types of natural disturbances, floods, drought, and inundation, and to a lesser extent by sedimentation and erosion. Most disturbances are not extreme and have no long-term effect. The microscale domain encompasses events occurring over the year and on the spatial scale of the pore, fissure, or channel. The processes take place generally during the annual hydrological cycle.

The chemical content of waters results from three factors: (1) type of the rock (e.g., mineralogy and grain size) in contact with the flowing water; (2) the climate and, in general, environmental conditions, determining flow rate, temperature, pressure, etc.; and (3) the flow conditions, determining especially the presence of a gaseous phase and the time of contact between water and rock (i.e., residence time of water in the system). The first factor imparts the main geochemical characteristics of water.

All minerals and, consequently, all rocks are soluble to some extent in water, but some of them are more soluble than others. The solubility of a mineral (i.e., the quantity of dissolved minerals in water) depends on its nature, on physical variables (such as temperature and pressure) and, on water chemical content. However, mineral solution never is an instantaneous process. That is why time for water-rock contact partly determines the dissolved solids content of water. The longer the water-rock contact, the more mineralized the water. Some factors contribute to increase the solution velocity, such as the surface of water-rock contact and the flow regime. Water chemistry in its simplest form involves two-phase and three-phase systems (i.e., water–rock and gas-water-rock systems). Three phase systems are the more complicated, involving more reactions and equilibria, but they may record conditions for free surface flow or infiltrating water in the vadose zone and phreatic flow for lack of a gas face, because some of their chemical variables "keep in memory" the relations between solution and gas and between solution and rock. The CO_2-H_2O-carbonate system will be detailed because it is the best known and the most common example.

Of the cations found in most fresh-water systems, calcium generally has the highest concentration. Calcium in water is commonly called water hardness. The chemistry of calcium, although complicated enough, is simpler than that of the transition metal ions found in water. Calcium is a key element in many geochemical processes, and minerals constitute the primary sources of calcium ion in waters. Among the major minerals contributing to dissolved calcium in water are gypsum, $CaSO_4 \bullet 2H_2O$; anhydrite, $CaSO_4$; dolomite $CaCO_3 \bullet MgCO_3$; and calcite and aragonite, which are different mineral forms of $CaCO_3$.

Water containing a high level of carbon dioxide readily dissolves calcium from its carbonate minerals:

$$CaCO_3(S) + CO_2(aq) + H_2O \rightleftarrows Ca^{2+} + 2HCO_3^-$$

When this reaction is reversed and CO_2 is lost from the water, calcium carbonate deposits are formed. The concentration of CO_2 in water determines the extent of dissolution of calcium carbonate. The carbon dioxide that water may gain by equilibration with the atmosphere is not sufficient to account for the levels of calcium dissolved in natural waters, especially groundwaters. Rather, the respiration of micro-organisms degrading organic matter in water, sediments, and soil, accounts for the very high levels of CO_2 and HCO3- observed in water:

$$\text{organic matter} + O_2 \rightarrow CO_2 + H_2O$$

This is an extremely important factor in aquatic chemical processes and geochemical transformations.

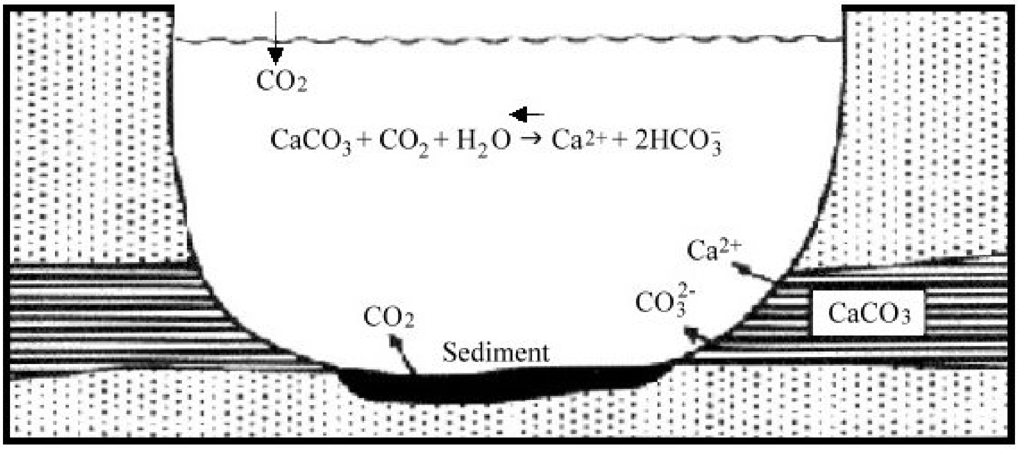

Figure 3: Three-phase system: Gas-water-rock

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Bibliography

Environmental Chemistry, S.E. Manaham, 5th Edition, Lewis Publishers, United States, 1991

Global Environmet Otlook 2000, UNEP , http://www.unep.org/geo2000/

Global Ecology, Colin Tudge, Natural History Museum Publications, London, 1991.

Groundwater Ecology, J. Gibert, D. Danielopol, J. A. Stanford Eds., Academic Press I Inc. United States, 1994.

Human Development Report 1993

UN (1993). Agenda 21: The United Nations Programme of Action from Rio, UN Publicatios, New York, United States, and Oxford, United Kingdom.

UNEP (1999). http://www.unepie.org/Cp2/declaration/home.html

UNEP, World Bank and NASA (1998). Protecting Our Planet – Securing Our Future: Linkages Among Global Environmental Issues and Human Needs, Watson, R.T, Dixon, J.A., Hamburg, S.P., Janetos, A.C. and Moss, R.H. (eds.). UNEP, Nairobi, Kenya.

World Bank, 1998. World Development Indicators. The World Bank, Washington DC, United States.