PHYSICAL PROPERTIES OF SOIL AND GROUND WATERS

Gusev Ye.M.
Water Problems Institute, Russian Academy of Science, Moscow, Russia

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Contents

Summary

Ground and soil water play an important role in Earth's biosphere. Ground water is actively exchanged with soil and surface water, in such a way that, river flow ground part forms about 25 % of the total river flow. Soil water is located, as a rule, in aeration zone, situating above ground water level. It plays an important role in land hydrological cycle forming (due to specification of its location on the boundary of atmosphere and lithosphere), exercises influence on climate formation and is the most important factor of existence and development of plant cover. The methods of hydrodynamics are widely applied nowadays for description of soil and ground water physical properties. The methods have the most flexible, developed and practical category system, allowing to effectively characterizing equilibrium conditions of different water phases in soil. Specifically, for estimation of water energy status in soil one can apply partial or specific vacant Gibbs's energy - chemical potential of water in soil, having special name - water potential in soil. In addition, soil water potential is usually equal to sum of three potentials -capillary-sorption, gravitation, and osmotic . Soil water capillary-sorption potential dependence on soil or ground moisture is very important characteristic, reflecting special features of structure and composition of soil horizon or ground layers. In case of equilibrium breach, connecting with appearance by some or other reasons of potential and temperature gradients (often named thermodynamic power), water flow appears in soil, and it is proportional to those powers. Water transition description in unsaturated soil is based on Richards's equation, using as well so important soil hydrophysical characteristics, as soil water conductivity and soil moisture diffusion coefficient. For detail mathematical modeling of water transition processes in aquifer and aeration zone it is necessary to know relations of soil water potential and soil water conductivity with soil moisture. There are many methods of experimental evaluation of those characteristics.

But labor-intensity of these methods forces to search common mathematical definitions of indicated relations, which use parameters range, identifying soil under consideration, and to create data bases by these parameters for different soil (specifically, such as HYPRES, STATSGO, NOAM-SOIL etc.).

1. Biosphere Role of Soil and Ground Water from Physical Point of View

Ground water is usually understood as water, which exists in terrestrial crust thickness in all physical states, lies in soil thickness, sediment rocks layers, and massif-crystal rock fractures. Its quantity is estimated as 23.4 millions km^3, and it comes close to 65 % of all surface water volume taken together. In addition, ground water of first aquifer from surface, which lies on nearest aquitard (it means ground complex, saturated by water and being able to give it, as a term “aquifer”), named unconfined ground water. Ground water is very well exchanged with soil and surface water, e.g. river discharge subsurface content is equal to about 25 % of total river discharge. Ground water provides half of fresh water which people use on Earth. Thus, it is difficult to overestimate the biosphere and economic role of ground water.

Soil water is suitably understood like water, located in soil porous space (that is to say, in land surface layer, having fertility) and manifest as moisture (as connected with soil constituents, as capable to move in soil profile), solid component in the form of ice in soil porous space, as well in the vapor state in the soil voids.

Soil water proportion in the total volume of land water is not relatively great (~0.06%). But the geo- and biophysical role of water on the Earth is no less than that of ground water. That role is connected with the boundary character of soil water localization. In fact, solar radiation coming to Earth and moving all the planet turnovers (the most intensive are atmosphere precipitation processes, hydrological cycle processes, as well as “life”, which according to Onsager and Morowitz are termed in combination as “connected bioelements circulation”), is transformed to other energy form in very thin planet layer, actually on a boundary between the atmosphere and lithosphere. It is significant that just there all four biosphere contents: atmosphere, lithosphere upper part, hydrosphere (in connection with hydrological cycle formation) and living substances of the continents are connected, because the thickness of “life film” covering the surface is very small; it is no more than some tens of meters above the terrestrial surface for forest land and penetrates to some meters into the soil depth.

The soil water is situated just in the above-mentioned zone of solar energy transformation and biosphere components connection. Due to this character the physical properties of soil water successfully reflect three most important aspects, determining their place in the Earth’s hydrosphere, are closely connected each to one another. In the first place soil water- is the most active link in surface water interaction. In surface hydrological cycle the soil layer is the so-called “water divisor,” determining the division of coming part of hydrological cycle (precipitation) into three discharging components: surface water flow, ground water flow and evapotranspiration, depending on heat-hydro-physical soil parameters and soil water and heat regimes. The second is conditioned by circumstance, that soil water – one of elements of the Earth’s climate system (which exercises most significant influence on climate formation due to special features of its localization on the border between atmosphere and lithosphere). The third aspect is determined by fact, that soil water is the most important factor of plant cover existence and development; that is to say of the first link in the trophic chain of terrestrial ecosystems. It is soil where subsurface root part of land vegetation cover is, providing as mineral substance inflow to plant tissue, as water inflow to leaves – its vaporization organs; that is why transpiration intensity (water vaporization from plant mezophil cell, which plays the part of hydrological cycle forming, atmosphere circulation, and first organic production) is determined in many cases by not only vegetation cover parameters, but also soil moisture supply dynamics. Soil in this case is specific reservoir of Earth's continental crust, making temporary regulation of vegetation cover water supply possible.

It should be given special consideration to the role of such important component of hydrological cycle as transpiration (water vaporization by vegetation cover). Evapotranspiration from land for all planet (80-90 % of it transpiration is) comprises about 2/3 of the precipitation falling on the continents. It seems, that such big water volume coming as precipitation on land surface, is wastefully discharged. Actually, for normal life-support the plant needs no more than 1-3 % of all vaporized water passing through it for plant tissue formation during photosynthesis and its saturation. The remaining 97-99 % goes to the atmosphere by vaporization and transpiration. It is like Niagara waterfalls used to fill a bathtub.

However, analysis of surface plant cover system, which contains all the living organisms including plants for which the essential condition of life, from the points of view of modern physics and theory of dissipative structures, is to export the continuously generated entropy by these structures, shows that it is not quite right. Quite the reverse, surface plants leaves mouthed system produced during the evolution, coordinate function of plants carbonic feeding with another not less important function like liberation from the surplus of the entropy produced by plant during the period of creating new structures by it with the help of rather specific biosphere process — transpiration very well. Actually, solar energy, incident on plant cover surface and degraded into heat, is moved away due to heat radiation, convection and transpiration. In addition, for most part of leaves surface of normal vegetating plant cover in the presence of heavy moisture, plant leaves overheating relative to environmental air in nature conditions is no more than $1\text{-}3^0$, but often plant temperature is equal to air temperature. Therefore in vegetation cover in total, energy expenditure for transpiration ought to very much exceed heat rejection due to convection, and the same due to effective radiation, which also is approximately proportional to difference between the leaves temperature and environmental air. Thus, under active vegetation condition, that is to say while new structures are formed, when demands to withdrawal of entropy produced by plant cover are very strong, transpiration is the main mechanism of its export.

It seems, it is a very inefficient method, because in addition plants spend water, which often is very difficult to obtain, in wasteful easiness. But transpiration is a very effective method of energy diversion from plant cover without any temperature increase. To divert the same quantity of heat without transpiration by convection or heat radiation, leaves cover ought to be heated till temperatures, significantly exceeding environmental air, and on hot sunny day, very much aiding in new structures organization, to be exposed to dangerous temperatures, even killing heat, that is to say to temperatures exceeding limits not only of photosynthesis depressions, but ferments and cell plasma structure forming existence. That is why, to avoid transpiration, surface plants could have another life biochemical base, allowing existence of life at greater temperatures. But due to the fact that biochemical evolution on the Earth is finished earlier than organism morphological divergence, one of the main special features of modern life becomes its biochemical union. Small composition of the main organic components, common for all living systems, allows that ecosystems effectively operate on difficult trophic levels. But it means that an overwhelming majority of organisms can exist only in very narrow range of medium conditions: temperatures, salinity, radiation levels etc.

Approximate range of temperatures of most organisms' existence (although there are exceptions to the rule) is from 0 till 40° C. Such temperatures were characterized for those reservoir parts, where chemical evolution took place and first living organisms were born. After life came into land in the Paleozoic age, live structures ought to develop so as to preserve inside temperature conditions as the same, because the main "life blocks" – amino acids, their bases, lipids etc. stay without any changes. For the highest surface plants the only way for the exit of sun radiation energy degrading to the heat without essential rising of the plants tissue temperature could only be the mechanism of phase transition of water – into steam on the mesophyl cell surface by transpiration.

The facts are as follows that transpiration turned out to be "point" of the connection of the two global circular dissipative structures, of the two giant "cog-wheels": physical water circulation in the system of soil – atmosphere and the circulation of the bioelements (carbonic, hydrogen, nitrogen, oxygen, phosphorus, sulfur) in the surface plants ecosystems. Making turnovers of the bioelements in the system of the green surface plants move is impossible without this connection. Inasmuch as green plants are the starting link in the trophic chain of the surface ecosystems, water circulation in the system of soil – plant cover atmosphere (the link of the soil water is the main), in fact "untwists" the bioelements turnover, that is to say life in the all system of the surface biocenoses.

2. Water Equilibrium State in Soil

Soil as the solid medium can be saturated or unsaturated. Soil is saturated if pores of the medium are full with liquid and if not they are not saturated. Zone of the deep underground water is always saturated. Higher than the saturated zone the unsaturated zone (aeration zone) is situated which belongs to the soil water and interesting for the agronomists, soil scientists and building engineers (for example in the case of the road bases drainage).

Analyzing and modulating of the water transition processes in the soil we should remember that physical water properties in this media differ greatly from water properties in the free volume. In the case of interconnection with the soil, water molecules are subjected to the powers of different features that restrict their movement and change energetic water position. Specifically energetic water position in the soil and ground is rather influenced by forces appearing on the surface division of soil solid phase (and the particles of ice at the negative temperatures) with the liquid and gas; surface curvature of the division between liquid and gas phases; gravitation; existence of the dissolved elements; temperature, mechanical pressure, for example, because of the activity of the higher stratums etc. It is impossible to express the resulting influence of all the different forces in such complicated systems as soil or ground by a summarizing vector of forces of water state. Owing to the latter, the methods of thermodynamic hydrophysics which are most flexible, developed and practical category system, permitting characterizing the conditions of the different water phases in the soil and ground effectively, are widely used for description physical properties of the soil and ground water. The statistic feature of pore area of the soil space, variety of forces, determining interaction of solid phase and dissolved substances with water, motivates thermodynamic description of system water-soil, diverting attention from exact mechanisms of interaction and allowing us to describe soil-hydrological processes, including moisture exchange between soil and plants, unconfined ground water and atmosphere, with the aid of several macroscopic variable quantities within the capacity of measurements.

Specifically, one can usually apply partial or specific vacant water Gibbs's energy in soil – chemical water potential in soil, so-called soil water potential Ψ for water energetic state evaluation in soil. In addition, for description of energetic state of water in soil, one can describe soil water potential in soil as sum of capillary-sorption soil water potential Ψ_r (depending on soil moisture), gravitation potential Ψ_g (depending on position height of soil sample) and osmotic potential Ψ_o (depending on concentration and composition of dissolved in water substrates)

$$\Psi = \Psi_r + \Psi_g + \Psi_o \quad (1)$$

One can obtain energy per mass unit (J kg^{-1}) as main unit of potential measurements In some cases it is comfortable to express potential as energy per unit volume (Pa). Finally, water potential is often obtained as energy to weight unit (hydraulic pressure). In this case its size is in meters (m). Soil moisture potential is often indicated as symbol pF, which in this case is its decimal logarithm (in addition Ψ is measured in centimeters of water column).

Soil water capillary-sorption potential dependence Ψ_r on soil or ground moisture θ is very important characteristic, reflecting the structure and composition special features of soil horizon or ground layer. That is why it is often called the main soil hydrophysical characteristic (MHC). It is important to note that, the function $\Psi_r(\theta)$ is complex due to hysteresis phenomena – different soil moistures may correspond to the one potential value depending on the history of moisture or drying conditions. Nevertheless, at present $\Psi_r(\theta)$ is successfully applied as so-called "passport" of obtained soil or ground in different questions of statics and dynamics of soil water to account for hysteresis phenomena without totally ignoring it.

Particularly, on the basis of this traditionally in soil sciences, hydrology and hydrogeology so-called soil-hydrological constants; for example, fade moisture, limited field soil moisture capacity etc are often evaluated. So, Ψ_r = -15000 J kg^{-1} corresponds to fade moisture (soil moisture, in which plants fade and even after their transition to moisture atmosphere their turgor pressure of cell capsule, providing phytoelements base function, is not restored). Potential, corresponding to minimal soil moisture capacity (in which soil moisture that is established in soil profile when the latter is moistened from surface and then superfluous water flows to underlying layers during 1-3 days), is often assumed close to – 333 J kg^{-1}, but for sand and sand-loam soils the absolute value of Ψ_r is a little less then 333 J kg^{-1} and for clay soils is a little more .

At soil temperatures below zero in winter, soil water capillary-sorption potential is determined mainly by soil temperature T_s (^oC) and is almost independent on its moisture, which is connected in this case with soil ice content Ic (m^3 m^{-3}) and with liquid water content u (m^3 m^{-3}) by the following relation:

$$\theta = \frac{\rho_i}{\rho_w} Ic + u \tag{2}$$

where ρ_i and ρ_w denote liquid water and ice densities, respectively.

Besides, content of unfrozen water in soil u may be approximately estimated according to following equation:

$$\Psi_r(u) \approx 1.2 T_s \quad \text{kJ kg}^{-1} \quad . \tag{3}$$

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Biographical Sketch

Yeugeniy M. Gusev is a Doctor of Science (Biology), Head of Soil Water Physics Laboratory, Institute of Water Problems of Russian Academy of Sciences. He is author about 120 publications. His field of scientific interests is mainly Hydrology including Soil Science, Hydrometeorology, and Ecology.