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Concepts on groundwater resources

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ABSTRACT

When dealing with groundwater and water resources in general, various conceptual terms are used by different individuals, experts and organizations. They are often applied without a clear–cut definition. This produces poor precision in the language used, misinterpretations and uncertain evaluations that make results difficult to compare. Proposing a terminology is not a simple task if it has to agree with both the hydrogeological processes and the related environmental issues involved. However, this is a task that has to be done. Lack of precise definition of terms can be found in the Water Plans carried out by the different Water Districts in Spain, as well as in the legal norms. This also happens in Ibero-America, although in some cases glossaries are included in the administration and legal texts. This paper presents a synthetic proposal, following the sequence of hydrological–hydrogeological processes, highlighting some of the commonly used terms. Some of them may coexist, but the others should be discarded. Some of the terms to be considered when referring to groundwater are: use, demand, consumption, recharge, resource, exploitation, intensive exploitation, water mining, and recovery time. The English terms are given, and their Spanish and Catalan trnaslation.

Keywords: groundwater, processes, reserves, resources, terminology.

Conceptos sobre recursos de agua subterránea

RESUMEN

Cuando se habla de agua subterránea y de recursos de agua en general, se utilizan diversos términos conceptuales por distintas personas, expertos y organizaciones. Este uso se hace frecuentemente sin una clara definición de los mismos, lo que conduce a poca precisión en el lenguaje, malas interpretaciones y evaluaciones inciertas, que hacen que los resultados cuantitativos sean difíciles de comparar. La propuesta de una terminología no es una tarea sencilla si ha de estar de acuerdo con los procesos hidrológicos y al mismo tiempo con los relativos al ambiente. No obstante, esta tarea se debe hacer. Se encuentra una falta de precisión terminológica en los Planes Hidrológicos llevados a cabo por los diferentes Distritos Hidrológicos de España, así como en las normas legales. Lo mismo sucede en Iberoamérica, aunque en algunos casos se incluyen glosarios en los textos administrativos y legales. Aquí se aporta una propuesta sintética, que sigue la secuencia de los procesos hidrológicos, resaltando algunos de los términos de uso más frecuente. Parte de ellos pueden coexistir, pero otros deberían ser desechados. Algunos de los términos a ser considerados, en lo que hacen referencia al agua subterránea, son: uso, demanda, consumo, recarga, recurso, explotación, explotación intensiva y tiempo de recuperación. Los términos están en inglés y se da la traducción castellana y catalana.

Palabras clave: Agua subterránea, procesos, recursos, reservas, terminología.

Introduction

Scientific and technical papers and reports on groundwater resources use terms that are often poorly defined. This makes it difficult to compare results and to know what the meaning of the evaluations and calculations is. This may lead to erroneous water and mass balances and uncertainty in decision making under water stressed conditions. Comparisons are still more difficult when considering surface water and groundwater resources together, and when other water sources are involved, which is the case in many areas, especially around urban areas.

Common terms to be considered are those referring to water use, groundwater resources, pathways for making water available, exploitation, quality and origin of water. In addition, climate related concepts of water resources may be affected by language uncertainties.

In what follows, the terms used for concepts are briefly considered after grouping them. This is done in the framework of water plans resulting from the current Spanish Water Act (TRLA, 2001), its later modifications, and derived legal norms, such as the Water Planning Regulations (RPH, 2007) and the Instructions for Water Planning (IPH, 2008). The incorporation into the Spanish water legislation of the European Water Framework Directive (DMA) of the year 2000, and the Daughter Groundwater Directive of 2006, has improved the definition of some concepts but others remain poorly defined. The fact of including this topic in an issue devoted to Ibero-America can be explained by the importance given there to the environmentally oriented European Water Framework Directive, some widespread wrong ideas about it, and the usefulness of their guides to confront water planning in other countries.

It is important to distinguish between extensive and intensive magnitudes in water planning and to measure them in the correct units. Extensive magnitudes and variables are commonly given in hm^3/year, and sometimes in m^3/day and L/s. The frequently uses symbol Mm^3 is meaningless in the metric system of units as the exponent affects all the preceding symbols and no that just the one to the left. This expression should be abolished. To make it equivalent to hm^3 it should be written M·m3. Extensive values are for a given area, generally a large one, and may refer to a downstream point for a given river basin or a down–flow section for an aquifer or along some specified boundary.

Intensive magnitudes and variables are the extensive ones when given relative to a unit of another magnitude, such as per inhabitant or per unit surface area. In this latter case, the resulting common units are m/year or mm/year, although in agriculture the m^3/ha/year is commonly used, which is equivalent to 0.1 mm/year. These magnitudes refer to a unit of time, and consequently are rates, although this is often not explicitly indicated and may produce some confusion as if the unit of time is not indicted the value could correspond to a given time lapse.

Reserve related terms correspond to volumes and are commonly given in hm^3 (10^6 m^3) and in the case of large figures in km^3 (10^9 m^3).

This paper includes mainly personal reflections directed to water plans and related documents in Spain, but also in other Ibero-American countries, such as Argentina, Chile, Uruguay and Brazil, considering what is the common language under the existing hydrological circumstances. Consequently, personal references dominate.

Different glossaries deal with hydrological terms, such as those produced by Aquastat (FAO), the US Department of Agriculture, the Dirección del Medio Ambiente (Spain), and Aldaya et al. (2018) enlarging that of the Water Observatory of the Botín Foundation. However, they frequently do not address the specificities of groundwater resources, and thus do not give the required accuracy in applied hydrogeology. A comparative discussion is beyond the scope and possibilities of this paper.

The first time a term is presented it is highlighted in bold, followed by the translation into *Castilian* (Spanish) and *Catalan*, in italics. This has been done as the paper is mostly directed to Spanish and Ibero–American readers.

Groundwater use

Water use related terms refer to the quantification of water utilization. Water use (*uso; ús*) refers to the water that is devoted to a given activity or process. It has to be distinguished between:

a. total or gross water use (*uso total* o *bruto*; *ús total* o *brut*), which is the water taken from a source, including water that is lost on the way (leakages, evaporation, derivations), and
b. net water use (*uso neto; net ús*), which is the water directly applied to the action or process; this is also called applied water (*agua aplicada*; *aigua aplicada*).

Water consumption (*consumo; consum*) or consumptive use of water (*uso consuntivo; ús consumptiu*) refers to the used water that does not return to the system, irrespective of quality and the changes in its timing. This refers mostly to water that has evaporated, discharged into the sea or to a river downstream of the uptake points, recharged in parts of the aquifer without later use and non–usable for environmental purposes. This consumption may be the consequence of the action or process or of artificial disposal that avoids or precludes further use due to non–acceptable or non–treatable quality in practice. This commonly refers to applied water, but may also refer to gross use; this should be specified. The difference between use and consumption is water that could be used again, although quality or salinity correction may be needed. Urban and industrial consumption is much less than use, but the two values are used in the case of efficient agricultural irrigation.

Water demand (*demanda; demanda*) is what a given user wants according to costs and circumstances. It equals or is greater than water use. It should be specified if it is at the source (gross) or at the application area or activity (net).

In Article 3 of the Spanish Water Planning Regulations (RPH, 2007), water use is defined as the different modes of resource utilization, as well as any other activity that has a significant impact on water status (*"las distintas clases de utilización del recurso, así como cualquier otra actividad que tenga repercusiones significativas en el estado de las aguas"*). Demand is defined as the water volume, in quantity and quality, that users are willing to acquire to satisfy a given production or consumption objective. This volume is a function of different factors, such as service prices, income level, kind of activity, technology and others (*"el volumen de agua, en cantidad y calidad, que los usuarios están dispuestos a adquirir para satisfacer un determinado objetivo de producción o consumo; este volumen será función de factores como el precio de los servicios, el nivel de renta, el tipo de actividad, la tecnología u otros").*

The values per person or unit surface, and per unit of time, are often called the dose (*dotación, dotació*). It should be specified if the doses refer to gross or net water use. The dose may change with time, so the time period should be given.

Return flow (agua de rechazo; *aigua de rebuig*), also called irrigation excess (*retorno de riego; retorn de reg*) in irrigated agriculture, refers to the non–consumed applied water which could be used again, part of which adds to aquifer recharge.

Groundwater resources and reserves

The concepts of reserve and resource are quite well defined in mining, for non–renewable minerals, including oil and gas. This is more difficult for groundwater as it is renewable in a human time scale, at least to some extent, in common situations. Thus, reserve and resource concepts have a different meaning, which also do not fully coincide with surface water concepts.

A first concept to be clarified is recharge (*recarga; recàrrega*). Recharge can be defined as the flow of water penetrating into an aquifer (or better, the saturated zone), coming from the surface. The penetration is produced through the water table at the unconfined part of aquifers. This water comes from diffuse infiltration of net atmospheric precipitation (rainfall and snowmelt) or by permanent, occasional or sporadic surface water infiltration, in rivers, wetlands, lakes, gullies and ravines. This water may enter directly or, in most cases, through the unsaturated zone. Diffuse recharge is mostly through the unsaturated zone. Infiltration (*infiltración; infiltració*) is a different concept as it refers to the water available at the land surface that penetrates into the ground. Recharge is less than infiltration, often much less, as evaporation and transpiration by plants have to be discounted. Calling infiltration "recharge" is an important source of confusion. Some hydrological models call infiltration the water leaving the soil zone and descending (percolation, *percolación, percolació*) toward the saturated zone. It may be better called in-transit recharge (*recarga en tránsito, recàrrega en trànsit*). This is often a source of confusion, and careful reading of the evaluation methods and what the hydrological models do is needed and demands a strict use of language from the beginning.

The exchange of water amongst aquifers, both those in the same vertical and the side ones should not be properly considered as recharge. In addition, seawater penetration into coastal aquifers is generally not considered recharge.

Groundwater discharge (*descarga; descàrrega*) refers to aquifer outflow to rivers as base flow, in springs, to wetlands and to the seashore. Groundwater withdrawal through drains and tunnels (water galleries) and pumped from wells and boreholes is artificial discharge. Evapotranspiration does not affect the aquifer but rather the soil water, except for shallow water tables and lagoons, in which case this is considered a discharge from the aquifer.

Groundwater total resources (*recursos totales, recursos totals*) refers to total inflow into the aquifer or aquifer system, that is to say, recharge and water transferred from on the same vertical or side aquifers and aquitards, and from surface water bodies, such as the sea and lakes. This needs a careful definition, as water inflow from surface water and from other aquifers is outflow from them. Otherwise, double accounting of water flow may occur. The decrease of aquifer water by evapotranspiration due to water table lowering, adds to water resources – although this may be ecologically unsound -, as well as the decrease of reserves when this is part of the management plan of the aquifer system. Available resources (*recursos disponibles; recursos disponibles*) are the total resources minus the flows to be preserved to maintain river and spring flow, lakes, wetlands, shallow water tables, and outflow to the sea to limit seawater intrusion and to keep salinity conditions particularly in littoral environments. This last definition is not universal and depends on local legislation and norms, according to the priority given to the ecological values of the environment. The former definition is that adopted in the European Union.

Recharge, discharge and resources are not aquifer or aquifer system properties, as they depend on exploitation conditions, especially when surface water is an important source of recharge or the lowering of the water table reduces evapotranspiration. So, their definition and evaluation should be accompanied by information on current aquifer status and well water abstraction distribution (Custodio et al., 2017b; RAEMIA, 2019).

Groundwater reserves (*reservas; reserves*), also called storage (*almacenamiento; emmagazematge*), is the total quantity of water in the aquifer or aquifer system, including that in the aquitards. In deep aquifers, the maximum depth considered has to be given. When saline water is present, it should by specified if reserves refer to total water irrespective of the quality or only fresh water is taken into account. In coastal aquifers, the saline water body is generally included in the reserves, but it should be specified if the offshore part is considered or not. Reserves depend on formation volume and total porosity. Water in the unsaturated zone is generally excluded, but can be singled out when this is relevant, as may happen in deep unsaturated zones in arid climates. A large part of the groundwater reserve cannot be abstracted as it is held in place by capillary forces when the water table goes down or if it is too slowly drained from aquitards or pores in blocks and small fissures in the case of hard rock formations. Groundwater that could be mobilized in a reasonable time is that found in easily drainable saturated formations, that is, in large connected pores and fissures. Abstractable reserves (*reservas captables o extraibles; reserves extraibles*) or drainable reserves (*reservas drenables; reserves drenables*) are the part of total reserves than could be abstracted down to a given depth and with a maximum salinity in a reasonable time. They depend on specific yield or drainable porosity (also depending on drainage time) and on exploitation conditions and water quality. The latter also depends on the technical and economic possibility of treating abstracted groundwater when its quality is impaired, even applying reverse osmosis or reversible electro–dialysis to brackish water.

When groundwater salinity is considered, several terms are in use to qualify it, without consensus on the limits, which may vary from site to site, according to local circumstances and water stress. Freshwater (*agua dulce; aigua dolça*) commonly refers to water that complies with the drinking water saline standards or is suitable for irrigation of most crops. If salinity is higher it is often called brackish water (*agua salobre; aigua salobra*), up to some g/L of total dissolved solids. If salinity is higher, up to around seawater salinity, the water is called saline (*salina; salina*). When salinity exceeds that of seawater the water is called hypersaline (hipersalina; hipersalina) and brine (*salmuera; salmorra*) when it approaches or attains the concentration at which halite may precipitate.

Renewable groundwater (*agua subterránea renovable; aigua subterrània renovable*) is the water in an aquifer system that has a residence time that is short according to a given time scale, which should be specified. This time is commonly years or some decades. Renewable groundwater often coincides with groundwater resources. Groundwater average renewal time or turnover time (*tiempo de revovación; temps de renovació*) is the ratio of storage to recharge rate. It is closely related with average residence time (*tiempo de residencia; temps de residència*) and average transit time (*tiempo de tránsito*; *temps de trànsit*) (Custodio et al., 2018; RAEMIA, 2019).

Groundwater that can be abstracted is water that can be taken for human use or that sustains ecological functions and the associated services when it outflows or the water table is shallow. This can be called mobile water (*agua móvil; aigua mòbil*), which is also called blue water (agua azul; *aigua blava*). Water in the unsaturated soil that can be used by plants or pedologic or soil water (*agua edáfica; aigua edàfica*), which is also called green water (*agua verde; aigua verda*), is not properly groundwater. The use of the terms blue water and green water, even if colloquial and widespread in non–specialized groups and for easier diffusion to non-specialized readers, do not really improve hydrological terms and, in some cases, they are less accurate than classical ones. Green water is not an especially useful term, as it does not point to usable water, although it is interesting for economic evaluation of crop production and for comparative evaluation of projects involving land use. Changes in land use may greatly affect recharge and consequently groundwater resources through changes in green water, but this is directly and accurately addressed in hydrological and recharge models. The concept of grey water (*agua gris; aigua grisa*) is not clearly related to water resources in water planning and remains a fuzzy one, which is difficult to apply to groundwater.

Groundwater exploitation

Groundwater exploitation (*explotación; explotació*), also abstraction, development (*extracción; extracció*) is the fact of capturing groundwater and bringing it to the surface to be used or as drainage. It is called intensive exploitation (*explotación intensiva; explotació intensiva*) when the rate with respect to the recharge rate under current exploitation conditions produces significant changes in the functioning and pattern of the aquifer system, including the relationships with surface and seawater, and the associated piezometric and water table drawdown (Custodio, 2012). The water table drawdown implies a reduction of groundwater reserves.

Strict groundwater mining (*minería del agua subterranea; mineria de l'aigua subterrània*) occurs when exploitation exceeds actual recharge and consequently there is a progressive decrease of groundwater reserves. Reserve depletion (*consumo de reservas; consum de reserves*) includes both the extraction-associated drawdown during the long transient stage of large aquifers and groundwater mining or continuous groundwater depletion (MASE, 2015; Foster, 1993; Foster and Loucks, 2011; Konikow and Leake, 2014). A practical approach considers the time, which is relevant for the management of the aquifer system. It is considered that there is groundwater mining when, after groundwater abstraction ceases, the recovery time to go back to the initial conditions needs a long time, which should be specified (MASE, 2015; Custodio et al., 2016a; 2016b; 2017a). Often this is one or two human generations. In coastal aquifers, the substitution of fresh water by saline water due to abstraction can be considered fresh water mining.

Seawater intrusion (*intrusion marina; intrusió marina*) has two meanings (SASMIE, 2017). One is the natural penetration of seawater in continental formations due the greater density of seawater. The other refers to the increased penetration derived from coastal aquifer exploitation and other artificial actions. This should be clarified, as the derived conceptual evaluations may be distorted. There is no specific term for each situation, and consequently appropriate adjectives should be added.

Terms that should be used carefully or discarded

A term frequently used colloquially and in the literature and reports is groundwater overexploitation, overuse and overdevelopment (*sobreexplotación; sobreexplotació*). It is used, explicitly or tacitly, to highlight the negative results from groundwater exploitation. *In extremis*, any abstraction could be qualified as overexploitation. Positive results are not taken into account. Therefore, it is currently a colloquial term without precise meaning and negatively tainted. Thus, its use should be discouraged and substituted by exploitation and intensive exploitation, accompanied by the explicit presentation of the effects (Custodio, 2002). In Spain "sobreexplotación" is a legal term that was introduced in the Water Act of 1985 and derived dispositions and norms (Molinero et al, 2011), but its meaning is poorly defined in the Act and the regulations. It is defined through the appreciated results of exploitation. The term is only marginally considered in the current Rewritten Text of the Water Act (TRLA, 2001 and later amendments), after transposing the European Water Framework Directive of year 2000 in the Water Act.

When referring to aquifer reserve depletion, the decrease is sometimes called use of non–renewable water (*agua no renovable; aigua no renovable*). This is mostly another colloquial term, as in most cases, these depleted reserves can be recovered after some time, as recharge exists, even if small. The recovery time may often be decades. Only in current very arid environments or in well-confined closed aquifers, non–renewability is a fact. Non–renewable groundwater is sometimes called fossil water (agua fósil; *aigua fòssil*), as it is considered the result of recharge in geologically past times and since then isolated from the water cycle. Although this is a possible situation, detailed studies are needed to properly apply the term. It is prudent to avoid this designation. The studies carried out in the Cordillera de la Costa, Antofagasta, in Northern Chile (Herrera et al., 2017a; 2017b) help in clarifying this aspect.

It is not unusual to qualify saline groundwater by giving it different names. Some of them are intruded or encroached seawater (*agua marina de intrusión; aigua marina d'intrussió*), old seawater (*agua marina antigua; aigua marina antiga*), connate marine water (*agua marina congénita; aigua marina congènita)*, evaporite dissolution water (*agua de disolución de evaporitas; aigua de dissolució d'evaporites*). All these terms imply accepting a genesis, which should be demonstrated. As this is often not the case, the qualification should be avoided.

Terms related to groundwater and climate

Groundwater resources and reserves depend on climate (IAH, 2012), which is one of the main factors determining recharge (RAEMIA, 2019), but not the only ones as soil properties, vegetation cover and storm runoff also play a key role. The generally large reserve of aquifers relative to resources is a key property for mitigation (*mitigación; mitigació*) of future water resource modification due to both uncertain natural and anthropogenic factors.

When carrying out studies and quantifications, different terms should be clearly differentiated, reflecting non-coincident circumstances. Climate variability (*variabilidad climática; variabilitat climàtica*) refers to long term climate changes produced in the past, whose effects may still persist and can be studied through different proxies. Climate fluctuation (*fluctuación climática; fluctuació climàtica*) refers to current short term changes, at year and decade scale. They correspond to what has been experienced or reconstructed from climate records and land use conditions. Climate fluctuation includes cycles of 10 to 50 years from a long time ago and which determine that the observed groundwater behaviour in short time spans may depart significantly from long-term average values (Custodio, 2018). Climate change (*cambio climático; canvi climatic*) refers to predicted climate changes in the coming decades, which are assumed to be affected largely by human impact on the atmosphere. This adds to normal fluctuation and the largely unknown long-term derive. Global change (*cambio global; canvi global*) is the result of human activities on environmental behaviour, which may greatly influence water availability and groundwater aquifer recharge through the modification of a series of factors which include land management, land-use actions, forest status, human population, living standards, and the trend to circular economy, amongst others. To study future changes scenarios (*escenarios; escenaris*) are set and must be well characterized. Otherwise, future groundwater changes are meaningless and comparisons cannot be made.

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