Limitations of climatic changes on aquifer vulnerability assessment

Limitaciones del cambio climático en la determinación de la vulnerabilidad de los acuíferos

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RESUMEN

Se ha realizado una revisión bibliográfica de los diferentes escenarios hidrológicos que cabe esperar como consecuencia del cambio climático. Se modificará el régimen de recarga de los acuíferos (capacidad de campo y procesos de escorrentía), la hidrodinámica del agua subterránea (profundidad del nivel piezométrico), las propiedades físico-químicas de las capas suprayacentes a la zona saturada y la calidad del agua de recarga. La acción individual y combinada de cada uno de estos procesos repercutirá sobre parametros geológicos e hidrogeológicos que se consideran en la caracterización de la vulnerabilidad (intrínseca y específica) y el riesgo de contaminación sobre acuíferos. Los mapas de vulnerabilidad y riesgo que se desarrollen en condiciones climáticas actuales deben adjuntar previsiones de situaciones futuras para que los planificadores y gestores de recursos hídricos basen sus actuaciones a largo plazo.

Key words: *climatic changes, groundwater, intrinsic vulnerability, specific vulnerability, risk assessment.*

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Introduction

One of the main objectives for hydrogeology in coming decades will be to supply policy makers and water managers with the tools for a better protection of groundwater resources, either in quantity or quality. With this idea the European Water Framework Directive 2000/60/EC for river basin management (European Commission, 2000) and more recently the Directive COM(2003)550 (European Commission, 2003) for protection of groundwater from pollution (known as *Groundwater Daughter Directive*) emphasized the necessity to maintain and improve the standards of water (groundwater) quality. One of the ways to reach these criteria is the use of groundwater mapping tools and among them the intrinsic and specific vulnerability mapping, hazards inventory and finally a map assessing the risk over the groundwater resources.

Vulnerability mapping has been widely applied in homogeneous aquifers due to the easiest monitoring and sampling program of needed parameters in vulnerability models (Secunda *et al.*, 1998; Fritch *et al.*, 2000: Gogu *et al.*, 2003; Edet, 2004) and more recently in carbonated (karstic) aquifers (Doerfliger *et al.*, 1999; Goldscheider *et al.*, 2000; Vías *et al.*, 2002; Kralik and Keimel, 2003).

As a non-measurable property of the aquifers, groundwater vulnerability must be inferred from surrogate information that can not be usually quantified (Vrba and Zaporozec, 1994). Furthermore, most of the geological and hydrogeological information only evolves in a long-time scale and so it is considered as “steady-state” information. One of the problems with the existing methods for groundwater vulnerability, either in homogeneous or heterogeneous media, is the absence of prevision on the climatic change, because it will change some of the geological and hydrogeological characteristics of aquifers. In addition, researches may produce intrinsic vulnerability maps for wet, average or dry precipitation years, but these climatic conditions are defined according to a present climatic situation. Besides that, the intrinsic vulnerability maps are only a part of the whole groundwater vulnerability assessment formed by intrinsic, specific and risk mapping, and climatic change will modify not only parameters of the intrinsic evaluation, but also properties exclusively considering in the specific groundwater maps, as temperature, organic matter, CO_2 content in the soil or oxi(hydroxides) of metals (Kapelj *et al.*, 2003).

Hydrology and climate change

Natural climatic change and alterations caused by anthropic influences will have consequences in rainfall regime (quantity and intensity of rainfall), temperature of the air (increases of 1’4 - 5’8°C for the year 2100) and increase of the concentration of substances with anthropic origin, i.e.: CO_2 and suspended particles (Intergovernmental Panel on Climate Change, 2001). Each of these causes, and their combined action, will produce changes in rainfall or evapotranspiration, hence in the hydrologic cycle, and these modifications will be reflected on changes in aquifer recharge regimes (soil moisture and runoff processes), groundwater hydrodynamics, physical-chemical properties of overlying layers of aquifers and quality of the water that recharges aquifers.

Consequences of these alterations are not clear since regional effects on climate may differ from the average global values, i.e.: in northern regions with lower average temperatures will be more rapidly affected that those regions with higher average temperatures (Moore *et al.*, 1997; Murdoch *et al.*, 2000) and in southern regions with hotter climates a decreasing in rainfall will have proportionally more impact in runoff and infiltration, compares to cold areas of Europe (Arnell, 1999).

Most of the analyses to achieve the impact of climatic change on groundwater vulnerability assessment are supported on global average values of hydrological and physical-chemical parameters of layers. But there might be different trends on these hydraulic changes depending on the geographical area in which they occur. The net result for useful rain has to be calculated taking into account processes of evaporation. Since evaporation is a parameter governed mainly by temperature of the air, in some areas the temperature positive gradient will be higher than the rainfall one and so, although an increase in rainfall were taking place, the net result will be a decrease in the total recharge. Also the reversal process is possible, more water resources in a context of rainfall lowering if the evaporation (temperature) decreasing gradient is also lower. So it is necessary detailed studies of changes in rainfall and temperature for each region to achieve changes in a local scale (Frei *et al.*, 1998). Although it is difficult to establish what processes will dominate in what regions, there is an accepted consensus on the main results that may act in areas of increase and decrease of rainfall recharge (Nemec and Schaake, 1982; Burn, 1994; Panagoulia and Dimou, 1996; Frederick and Major, 1997).

Consequences of a increasing recharge

The increment of recharge (mainly in autumn and winter and to high and medium latitudes of continental regions) may yield an increase of the water flows and water velocities, with positive and negatives results.

Some of the positive consequences is the dilution of the point-source pollutants and an increase of the water storage in the aquifers, which it would minimize the already mentioned contamination episode. Among the negative consequences should be selected a probable increase in the contamination mass from non-point source. The increase of water velocities coupled to higher volumes of water would be associated to lower residence times and lower contact time between water and solid for attenuation reactions take place, hence a decrease of the effectiveness of natural attenuation of the contaminants. This latter point is stressed by the fact that water levels would be closer to the ground surface and the pollutants path from ground surface to the resource will be shorter. Also enlarging the rates of runoff, erosion will be increased, and therefore, the infiltrated water will load more chemical substances, nutrients and clays and colloidal transport.

Consequences of a decreasing recharge

In regions with increasing trends of air temperature (more evaporation) and greater CO_2 concentration, the primary effect should be a more rapidly growing of plants, with more surfaces for transpiration (Gleick, 1987). This might cause a decrease of flows and runoff, favoring the slow velocities of the running water.

One of the best situations in this framework is a higher residence time of water (and contaminants) in the non saturated zone of the aquifer because of a deeper position of the water level, what favors the natural attenuation reactions. The protection also comes because the field capacity stays for longer below the water saturation value, preventing pollutant infiltration, with an increasing interaction time water-soil. Finally, the non-point source contaminants will be diluted with less volume of water and as a consequence, less mass will be infiltrated in the aquifers.

Among the negative effects there exits a well established consensus for considering that the final concentration of the point-source contaminants will be higher, due to the limited volume of water for dilution, also a decreasing volume of the water stored in the aquifers implies an increase in the maximum concentrations reached in every contamination process. In arid or semi-arid regions a decrease of flows will increase the salinity and temperature of the water and with a bigger anthropic pressure over the water resources.

Change of layer properties

Effects on the climate change are not only translated to hydrodynamic changes of the water; the physical-chemical properties of the protective layers, besides the groundwater quality, can suffer changes. Climate changes, involving changes in temperature and hydrology, affects biological, chemical and physical processes in soil, since it is the most external layer of the aquifer, but these changes not always take place in the same direction, for which detailed studies in every region are necessary to estimate the direction of the change.

The increase of temperature may change chemical processes with an increase on the weathering rates of minerals which releases trace elements (including calcium, magnesium and potassium) and more alkalinity to the water, and variations in the organic matter content.

The organic matter content in the soil is one of the most important factors for contaminants retardation, and so the total mass in the soil is one of the key factors to be measured or assessed. The balance between mineralization and supply of organic matter will affect the quantity of organic carbon in the soil. The higher the temperature, the highest its mineralization and therefore, it will be produced a net decrease of the organic content of the soil. But if the increase of the temperature is combined with a rainfall rising trend, the net result will be an increment of biomass in the soil. So it is possible to find two effects, one increasing and the other one decreasing the organic matter content in the soil. The predominance of one of the processes will change depending on the climatic change that prevails in every region of study.

One of the most important factors that may be influenced by climatic changes would be the capacity of the soil for sorption of chemical substances by use of organic matter and clay content (potential sorption). A soil, in a climate frame that favored the accumulation of organic matter, would have more capacity for sorption of pollutants, and the degradation and retardation reactions would be more effective, having increased the residence time of substances in this layer. To summarize, the specific vulnerability would be reduced, since pollutants are attenuated in the overlaying layers. If, in the reversal climate frame, the soil is losing its organic matter, the system will also lost some potential sorption capacity and with it, the attenuation of contaminants in the soil.

The oxidation of soil sulphur species, in regions with severe droughts or high frequency of them will produce an acidification of the soil and water due to the oxidation of the reduced species of organic sulphur in the soil.

Higher toxicity and bioaccumulation of metals in water. Any increase in the temperature of the air would also increase the biological activity and the bioaccumulation of metals in the organisms. However, this increment could produce an improvement of water quality, since more metals will be accumulated for longer periods in the organisms.

Change in groundwater properties

Climate change may alter the water quality by four ways: (1) increasing air temperature, (2) alteration of rainfall regime, with its changes in volume and velocity of flows to the aquifers, (3) atmospheric deposition of acid substances with an anthropic origin and (4) increase of CO_2 concentration of the air. Each one of these factors, and theirs interrelation, could vary in a drastic way the quality of the water resources.

The increase of temperature of the air, even without changes of the rainfall, may increase the temperature of the water and hence a decreasing in the concentration of dissolved O_2 and CO_2 (Gleick, 1987) though in case of CO_2, this process could be masked by the increase of its concentration in the atmosphere. The decreasing concentration of O_2 has a direct consequence in the oxidation processes of contaminants.

In regions with higher air temperatures the natural biomass production (organic matter) will be enhanced. In a similar way with contamination episode with organic matter (landfill or sewage system leakage), this “extra” organic matter will need more oxygen to be degraded, so the net result will be less concentration of dissolved oxygen and a lost in the self-cleaning capacity of the aquifers.

Temperature is a master variable in all the chemical reactions, so any process in the soil will be affected if temperature increase, and this will have an associated change in the concentration of species and ions in water and an alteration of the hydrogen ions concentration (pH) in soil and water.

Changes in volume and velocity of flows to the aquifers have also consequences in the quality of the water (Panagoulia and Dimou, 1996). A reduction of the flows will give rise to an increase of the salinity and to a reduction of the total mass of oxygen, whereas an increase of flows will produce more dissolved oxygen in water, but also more erosion in the recharge areas and more natural organic and chemical substances production due to the increase of the river load. Thus, it would be able to have more nutrients, and more oxygen would be needed for the attenuation processes.

The atmospheric deposition of acid substances with an anthropic origin over the soil may reduce its pH. Metals, including nutrients of the soil, could be mobilized towards the non saturated and saturated zone of the aquifer wit a severe affection in the soil nutrient balance. Also, the recharge water infiltrating through the soil will be acidified, releasing hydrogen ions to deep zones in the aquifer.

The increase of atmospheric CO_2 concentration will alter the calcocarbonic system (Norton *et al.*, 2001), because water will be charged with more P_{CO2}, and the system may be adapted to the new conditions. Dissolution rate of carbonate minerals will be probably increased and groundwater from carbonated aquifers will have more mineralization.

Conclusions

The concept of vulnerability and risk are theoretical but useful for the protection of aquifers against human activities with a potential capacity of contamination and an important tool for water policy makers and water managers. Into this conceptual framework the characterization of all kinds of vulnerabilities (intrinsic or specific) or risk is done by an approximation with steady geological and hydrogeological parameters; sometimes with measurements in the field (lithology, physical-chemical parameters of soils) or assuming mean values, either because it is not possible to measure in the field (thickness or physical-chemical parameters of non-outcropping beds) or due to the difficulty of compilation in all the outcropping area of the aquifer rock (primary and secondary porosity or hydraulic transmisivity, among others). With all these group of parameters it is assumed a logical steady state of the values; however, there are parameters with seasonal changes. These parameters use to be of hydrological origin, i.e.: value and regime of rainfall, depth of water level or physical-chemical parameters of spring waters. The variation in the hydrogeological parameters, mainly in the thickness of the non-saturated zone as response to the seasonal and annual recharge, allows the assessment of vulnerability and risk for humid, average and dry rainfall periods. This kind of mapping intends to display the different situations of vulnerability that a region may suffer with the climatic variation.

This theoretical outline might be modified as a consequence of the change in parameters that were considered fixed in time and the emergence trends in hydrogeological factors as a result of the climate change. The natural climatic change and its acceleration due to the human activities will be the reason for an augment in the air temperature, concentrations of atmospheric gases and atmospheric deposition, as the most principal effects. The individual and combined effects of these changes will modify the rainfall regime and factors which figure as part of the hydrological cycle, i.e.: evaporation rate, runoff, infiltration or moisture in the soil. Additionally, they are supposed to provoke changes in the physical-chemical properties of overlying layers, just the layers that act as the first shield in a contamination event. The final consequences of the climatic variations will depend on the region because different climatic trends will take place; therefore, it is necessary to develop detailed studies about the rainfall and air temperature evolution, to reduce the uncertainties in the basic parameters needed for the vulnerability and risks assessments. Furthermore, it would be worth to append to the present vulnerabilities and risk maps, a kind of maps in which it will be taken into consideration future climatic conditions depending on the area. Hence, policy makers and water managers decisions concerning water resources would be more useful because it will be based also in future situations.

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