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3.1.4 Groundwater and climate change

SARA VASSOLO

SUMMARY: *Groundwater is world-wide one of the main resources for the drinking water supply. Further, groundwater is the only possibility of supplying water with adequate quality in rural areas or arid regions. But even in urban regions the use of groundwater is up to now the most economic way of supplying drinking water of good quality. Groundwater is a natural resource that renews depending on the local climatic conditions. The typical way of groundwater renewal is by seepage from rain through the geological formations in the underground. However, recharge can also be obtained by seepage from surface water like lakes, ponds, rivers, or even locally by artificial recharge.*

From a global prospective, groundwater is one of the main sources for drinking water supply .[1] Furthermore, groundwater is often the only source of good quality water for rural areas or arid regions. Even in urban regions, groundwater can be the most economic way of obtaining good quality water.

Groundwater is a natural resource that generally replenishes depending on the local climatic conditions. The typical mechanism for groundwater replenishment is by seepage of rainfall through surface geological formations. However, groundwater recharge can also occur by seepage from surface water bodies, such as lakes, ponds, and rivers, or by artificial recharge.

Groundwater recharge

Precipitation reaches the Earth surface either as rain or as snow. A portion of this rainfall directly evaporates into the atmosphere. The remainder infiltrates in the ground rather rapidly- or with some delay as is the case with snow. In areas with dense vegetation, up to 100% of the infiltrated water can be taken up by the roots in the unsaturated zone and transpirated back into the atmosphere. In arid and semi-arid regions with scarce vegetation, capillary forces can lead to large losses (up to 100%) of infiltrated water in the unsaturated zone. Depending on the terrain steepness and the degree of weathering of the ground surface, the infiltrated water can either flow back rapidly to the surface – a mechanism called interflow, or further downwards to reach the groundwater surface and the aquifer.

Independent from recharge processes, the following climate-dependent precipitation characteristics have a decisive effect on the groundwater recharge:

- Type, i.e. rainfall or snow
- Intensity, i.e. downpour or intermittent rainfall
- Areal distribution, i.e. local or regional
- Seasonality, i.e. during or outside the vegetation period

Climate scenarios and their influence on the groundwater recharge

All climate models predict a temperature rise that will surely enhance the evapotranspiration, which, in turn, will increase the air humidity and cloudiness and thus lead to more precipitation. The climate models HadCM3 (POPE et al. 2000) and ECHAM4/OPYC3 (ROECKNER et al. 1996) for example predict for the period 2061–2090 and the IPCC SRES A2 scenarios[2] (ALCAMO et al. 2003) an increase in the long-term annual precipitation of about 5%. *Fig. 3.1.4-1* presents a comparison of the changes in long-term average precipitation and their distribution predicted by both models.

The models produce contrary results for a stripe from North Africa to central Asia and the Gibson Desert in Australia (dark grey areas)[3]. A decrease in annual precipitation is expected along the southern rim of the Mediterranean Sea and most of the Arabic Peninsula, south-western Africa, the Atacama Desert, Patagonia and east South America, and the outskirts of the Gibson Desert in Australia (horizontal stripes). These areas practically coincide with areas that are currently arid (BERNHARDT 2003). Both models predict an increase in annual precipitation (light grey areas) for the northern part of the northern hemisphere, part of central Asia, and central Sahara. But both models predict no changes (< 5%) for many large regions throughout the world (vertical stripes).

However, the evaluation of changes in the long-term mean annual precipitation is not adequate to describe changes in groundwater recharge. It is the seasonal distribution of the precipitation that drives groundwater recharge. An increase in winter precipitation will surely lead to an increase of recharge because of low evaporation losses due to the low temperatures and the low vegetation activity. The changes in winter precipitation for 2070s compared to 1995 estimated under the assumptions of the IPCC SRES scenario A2 using ECHAM3/OPYC4 and HadCM3 are shown in *Fig. 3.1.4-2* and *-3*, respectively. The average monthly precipitations were calculated considering a series of 30 years, assuming the period

S.Vassolo@bgr.de

1961–1990 for current conditions (NEW et al. 2000) and the period 2061–2090 for the 2070´s.

Both models estimate an increase in winter precipitation for the northern part of Europe and Asia, but the results for North America are contradictory. While a decrease in winter precipitation (up to 50%) is calculated by ECHAM4/OPYC3 for central Canada, HadCM3 estimates an increase. Further, ECHAM4/OPYC3 calculates a decrease in winter precipitation for the whole eastern coast of USA, while HadCM3 estimates a decrease in the west and central parts of the country.

Model results for Central and South Europe are also contradictory. ECHAM4/OPYC3 calculates a decrease in winter precipitation and thus a decrease of groundwater recharge, which would further deteriorate the water scarcity in those areas. However, the HadCM3 model estimates a general increase in winter precipitation, except for South-west Spain and Italy.

Both models show relatively similar results for South America, although the area with a decrease in winter precipitation calculated for the Amazons region is larger in the case of the HadCM3 model. However, in this region it is not only the winter precipitation that leads to groundwater recharge. Due to the fact that both the precipitation and the temperature are relatively constant along the whole year, the recharge is season-independent. *Fig. 3.1.4-1* shows that both models do not expect any changes in the long-term annual precipitation. For the northern part of the Patagonia, the HadCM3 model calculates a much larger area with decrease in the winter precipitation than the ECHAM4 model. This region is currently characterised as an area of low precipitation that depends on groundwater supplied irrigation. Future decreases in winter precipitation would certainly worsen the situation.

Both models predict a decrease in winter precipitation for the Mediterranean rim in North Africa, no changes for the Sahara, an increase for the equatorial region and a decrease in the southern part of the continent, although this decrease is somehow stronger under the HadCM3 model. Both models predict no changes for Asia, except for India. ECHAM4/OPYC3 calculates a decrease, while HadCM3 estimates an increase in winter precipitation.

Both models calculate a decrease in winter precipitation for Indonesia and Australia, but this decrease is somehow stronger under the ECHAM4 model.

DÖLL & FLÖRKE (2005) modelled groundwater recharge at a global scale for the 2050's, based on climate data from the two climate models described in this paper. They worked with four different IPCC scenarios, but found out that all of them predict similar results which, in general terms, coincide with the outcomes described in this chapter.

Climate change and salt intrusion in coastal aquifers

In addition to effecting groundwater recharge, climate change would have effects on groundwater quality. The coastal aquifers are subject to constant pressure from sea water, but there is equilibrium between salt water and freshwater as long as there is sufficient groundwater recharge. However, salt water intrusion is already a problem in many regions of the world, mainly caused by aquifer over use. Aquifer over pumping leads to a steady drop in groundwater levels. Thus, the hydraulic pressure (head) of freshwater decreases allowing the flow of the salt-freshwater front inland (*Fig. 3.1.4-4*), as is presently the case for example at coastal aquifers in Spain, Germany (see Chapter 2.8) and the Netherlands. It is clear that the salt water intrusion problem will worsen if groundwater recharge decreases.

Climate models predict a future temperature increase that will probably lead to a melting of the ice caps in the Polar Regions and the glaciers. This over proportional availability of water will result in a rise of the ocean level[4] . The combination of all 35 IPCC SRES scenarios calculate a sea level rise between 0.09 and 0.88 m (in average 0.48 m) up to 2100 (IPCC 2001). Such a rise would not only flood large coastal regions, e.g. Bangladesh, but also make many islands entirely submerge and disappear (Nawrath 2003). Also the coastal aquifers would be severely impacted, as a sea level rise would increase seawater intrusion into freshwater coastal aquifers (*Fig. 3.1.4-5*).

Conclusions

The issues described above indicate that climate change could affect not only the quantity but also the quality of groundwater. The future availability of groundwater is defined by the future trends in winter precipitation and the resulting recharge. Unfortunately, it is still unclear how – and if – the amount and distribution of winter precipitation will change. The two models included in this work predict an increase in temperature, which would lead to enhanced evapotranspiration and thus air humidity, resulting in increased cloudiness and precipitation. But the models provide contradictory predictions when it comes to the regional distribution of the precipitation.

Groundwater quality could also be affected by a temperature rise. Higher temperatures could cause, among other things, a sea water level rise and the resultant intrusion of sea water into the coastal aquifers. In this way, sea water could flow into the extraction wells and render well useless for future water supply.

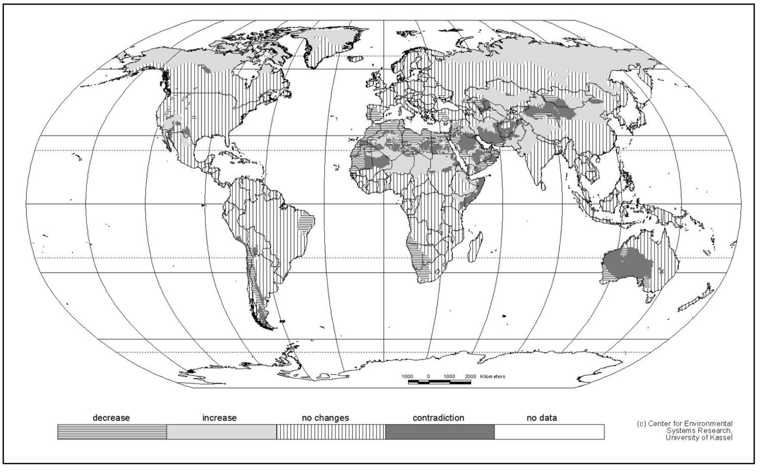

Fig. 3.1.4-1: Comparison of precipitation predicted by ECHAM4/OPYC3 and HadCM3 models for the 2070s and under the assumptions of the IPCC SRES scenario A2.

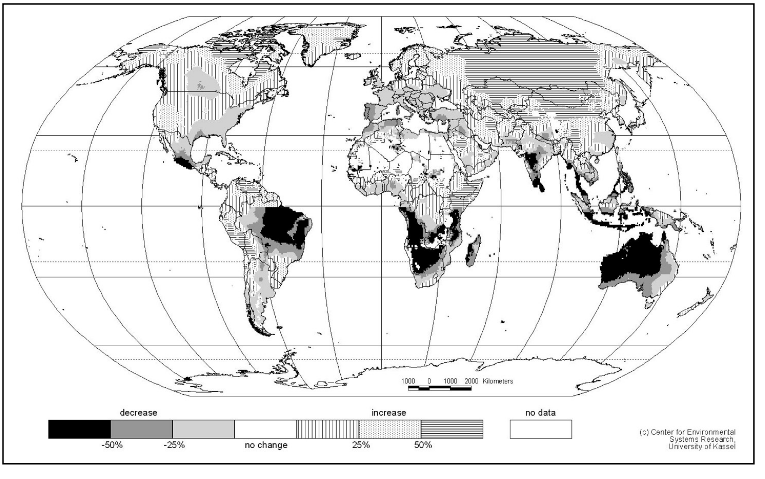

Fig. 3.1.4-2: Changes in winter precipitation for the 2070s compared to today, calculated with the ECHAM4/OPYC3 model and the IPCC SRES scenario A2 assumptions.

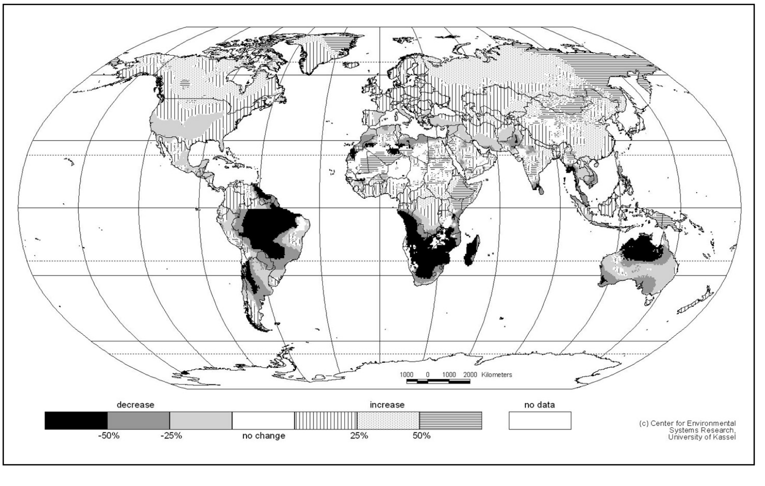

Fig. 3.1.4-3: Changes in winter precipitation for the 2070s compared to today, calculated with the HadCM3 and the IPCC SRES scenario A2 assumptions.

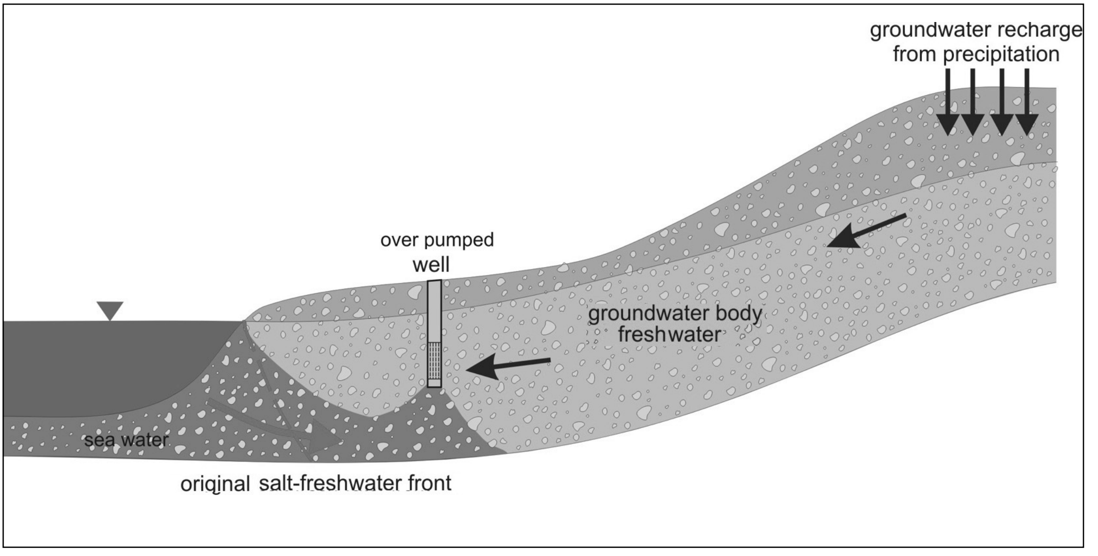

Fig. 3.1.4-4: Salt water intrusion due to over pumping.

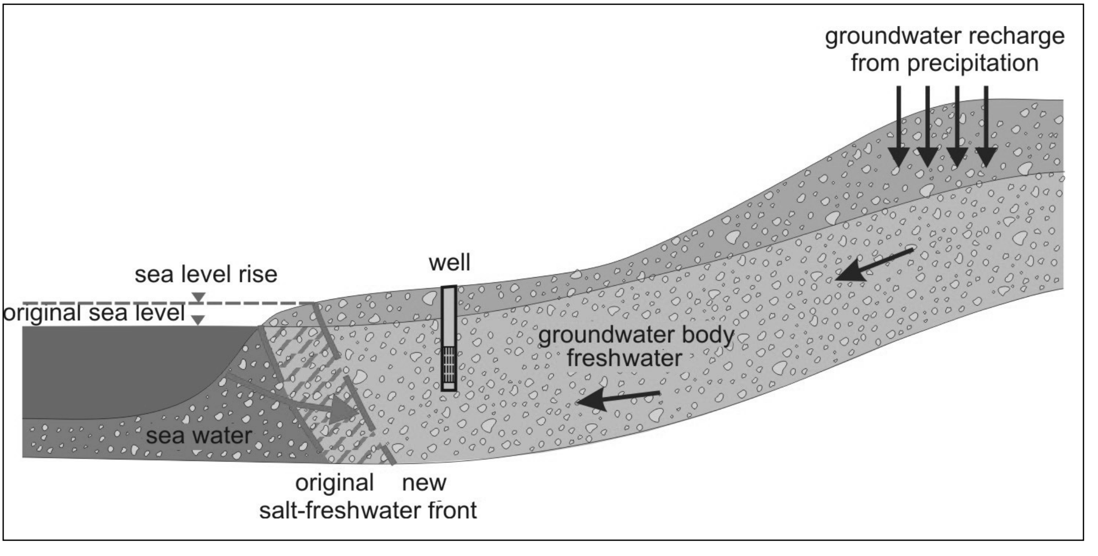

Fig. 3.1.4-5: Salt water intrusion due to a sea level rise.

[1] After FOSTER & BURKE (2003) 50% of the global domestic water demand is covered by groundwater.

[2] IPCC SRES scenario A2 describes a heterogeneous world with considerable regional differences. The birth-rate converges slowly between regions, which leads to an ongoing increase of the world population. The economical development, GDP increase, and technological transfer are regional-dependent (IPCC 2000).

[3] These areas are presently characterised by low precipitation. Thus, small changes in the precipitation figures are over interpreted.

[4] Relative changes in sea level are caused by a combination of different more o less complicated physical processes: changes in sea water density, vertical movements of the Earth crust, changes in the size of the ocean basins (STERR 2001). A sea level rise due to temperature increase will be caused by ice melting, enlargement of the upper sea layer, continental rise and dropping of coastal regions ♦