

What will climate change mean for groundwater supply in Africa?

By Roger Calow (Overseas Development Institute) and Alan MacDonald (British Geological Survey)

One of the key uncertainties surrounding the impacts of a changing climate in Africa is the effect that it will have on the sustainability of rural water supplies. Of Africa's population of 900 million, roughly 60% live in rural areas and most – perhaps 80% – rely on groundwater-based community or household supplies for domestic and other water needs (JMP, 2008). Understanding the impacts of climate change on groundwater resources is, therefore, of critical importance, yet is often ignored in development debates – including those on water supply and management.

This Background Note attempts to fill in some of the gaps and identify the most pressing research needs. The main focus is on domestic supply – water used for drinking, cooking and washing – but the note also deals briefly with groundwater irrigation and climate change.

The importance of groundwater

Why are rural water supplies in Africa dependent on groundwater? There are several reasons. First, groundwater can be developed close to population centres at relatively low cost, a major advantage for meeting dispersed rural demand. Second, it is, in general, more reliable than surface water: sub-surface aquifers can

often store much larger quantities of water than their annual recharge, with the result that reliable supplies can be maintained even during periods of low rainfall. This effect is sometimes referred to as the buffering capacity of groundwater, and contrasts with the relatively 'flashy' behaviour of surface water sources. Finally, groundwater tends to be of good quality, as it is protected from surface contamination (MacDonald et al., 2005).

In Ethiopia, for example, where roughly 75% of the population do not have access to improved water or sanitation, the government's plan to achieve full coverage by 2012 depends on providing villages, scattered over a vast area, with low cost groundwater supplies. And in Malawi, where roughly 72% of the rural population do not have access to improved drinking water sources, the government's National Action Plan for Adaptation (NAPA) to climate change identifies improved access to drinking water as a top priority.

What of irrigation in Africa? Away from the Nile, irrigation development has proceeded very slowly, growing by only 1% per year between 1995 and 2005 (FAO, 2006). The relative contribution of groundwater is difficult to estimate, but is probably very small: perhaps only around two million hectares, contributing to the livelihoods of 1.5 – 3.0% of the continent's population (Giordana, 2005). A comparison with Asia suggests room for growth, and groundwater irrigation has key advantages in terms of reliability, the scope for opportunistic development across wide areas and controllability. A key question is whether climate change will open up groundwater development for irrigation or simply put more aquifers, and other users, under stress.

Climate change scenarios

There is considerable uncertainty surrounding the future of Africa's climate, as reported in the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) (Christensen et al., 2007). The results of many of the different climate prediction models differ widely, and the models have difficulty in reproducing observed climate patterns for the past 50 years. Nonetheless, certain climate futures are being predicted with greater confidence (Christensen et al., 2007).

First, *average temperatures are likely to increase*. Hulme et al. (2000) show that for Africa as a whole, warming in the 20th Century occurred at a rate of about 0.5°C across the century, and that the rate of warming increased in its last three decades. In future, based on predictions under the medium-high greenhouse gas emissions scenario, annual mean air temperature between 2080 and 2099 is expected to be 3-4°C higher than it was between 1980 and 1999.

Second, *annual rainfall is likely to fall in the northern Sahara and in southern Africa, and is likely to increase in the Ethiopian Highlands*. Wider predictions are difficult to make as changes in precipitation are much less certain than those for temperature, particularly for the Sahel and the West African coast. The four African regions used in the regional analysis of IPCC (2007) are large and climatically heterogeneous, and while higher resolution analysis is clearly needed, '...the extent to which current regional models can successfully downscale precipitation over Africa is unclear.' (ibid). Downscaling to the level of large river basins with current circulation models may produce more hydrological 'noise', rather than clearer insight.

Finally, *rainfall is likely to become increasingly unpredictable in terms of both intensity and duration*, with increases in the frequency of extreme events - droughts and floods. Mean annual rainfall is already highly variable across Africa, ranging from almost zero over parts of the Sahara to around 10,000 mm in the Gulf of Guinea. Inter-annual and seasonal variability is likely to increase.

Impacts on groundwater resources and rural water supply

The occurrence of groundwater depends primarily on geology, geomorphology and rainfall – both current and historic. The inter-relationships between these factors create complex patterns of water availability, quality, reliability, ease of access and sustainability. Climate change will superimpose itself by modifying rainfall and evaporation patterns, raising questions about how such changes may affect groundwater availability and, ultimately, rural water supplies.

The balance between supply and demand

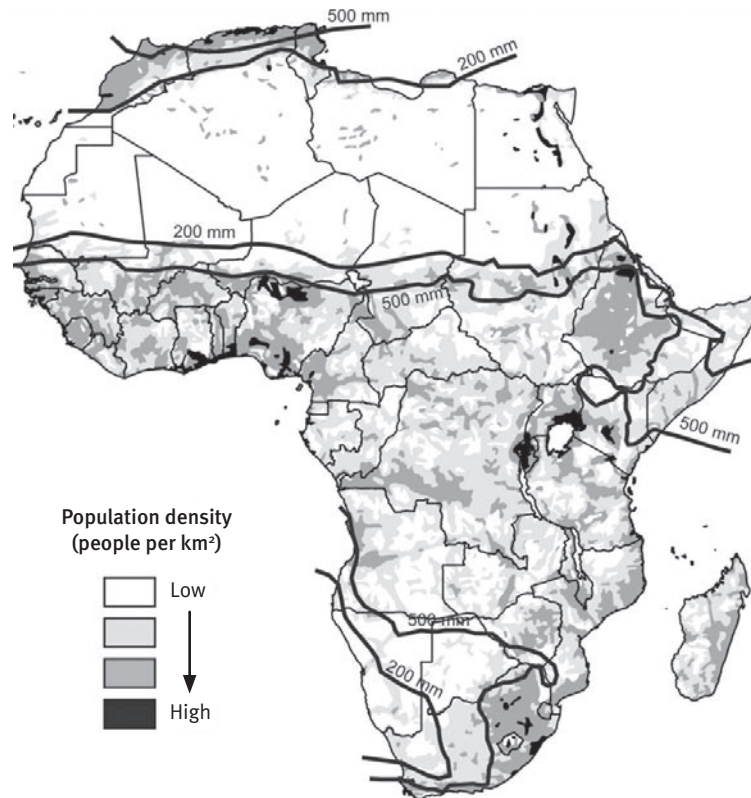
Changes in precipitation and evaporation translate directly to shifts in soil moisture deficits, surface water runoff and groundwater recharge. Quantifying these relationships is complicated, however, even where good data exist. Annual rainfall is clearly important, but factors such as the timing, intensity and duration of rainfall events in relation to temperature, soil-vegetation conditions and land use are also significant, as is the storage potential of underlying aquifers. Nonetheless, we can draw some tentative conclusions from rainfall maps (Figures 1 and 2) and knowledge of existing groundwater conditions and withdrawals.

Looking at Africa as a whole, we can suggest three broad rainfall-recharge zones. In those areas with annual rainfall of less than 200 mm, little or no current recharge is likely to occur (Eilers et al., 2007). In those areas with rainfall in the range of 200-500 mm per year, up to 5% (25 mm) may contribute to groundwater recharge, although much will depend on the timing and intensity of rainfall events (Edmunds et al., 2008). In areas where annual rainfall is greater than 500 mm per year, significant recharge (5-10% of rainfall, or 25-50 mm per year) may occur in most years. This approach is very much a simplification and based on few studies. Only with increased knowledge of recharge processes and aquifer responses will we be able to make more confident extrapolations over Africa.

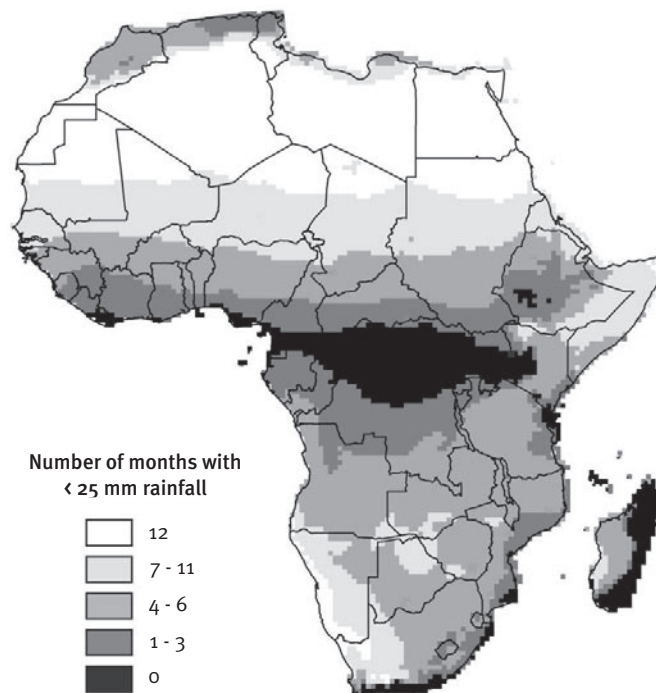
How do these preliminary figures relate to rural water needs? Domestic supply is not a major user of water, and the amount of water that can be withdrawn from aquifers is limited by the yield of individual sources. Most hand pumps, for example, have a yield of 5-10 m³ per day. If spread uniformly across Africa, these would require recharge of less than 3 mm each year to supply water for all (Wright, 1992; Carter and Alkali, 1996). Even with a water point spacing of 500 metres – significantly greater than current averages – the recharge required to sustain a simple well or borehole is less than 10 mm per year (MacDonald et al., 2008a).

Considering water for domestic supply only, people living in areas where rainfall is currently less than 200 mm per annum are, in effect, mining groundwater that is not being actively recharged from contemporary rainfall. In these sparsely populated areas, groundwater supplies are typically located in large sandstone aquifers where there is enough storage to meet domestic needs, or in some cases to support commercial irrigation (e.g. Libya). Groundwater sustainability in these areas is unlikely to be affected further by climate change.

Community water points in areas where annual rainfall is between 200 and 500 mm per year can,

Figure 1: The relative population density of Africa relative to average annual rainfall, 1951-96

Source: MacDonald et al. (in press).

Figure 2: The average length of the dry season in Africa (1961-1996)

Source: Calculated using data from New et al. (1999).

in general, sustain abstraction from ongoing, irregular recharge *under current conditions*. Boreholes can, therefore, be drilled in aquifers with high storage, and also in poorer aquifers where storage is more limited and annual recharge is required to renew the resource and sustain supply. In these areas, however, there is a fine balance between recharge and domestic water demand, and sufficient recharge may not occur every year (Eilers et al., 2007). Hence any reduction in annual rainfall, and/or changes in the timing, intensity and duration of rainfall events, may cause more sources to fail for more of the time - particularly those unimproved sources tapping shallow aquifers in areas with a long dry season (Figure 2) (Calow et al., 1997). Roughly 90 million people currently live in this rainfall zone (Figure 1).

In those areas where annual rainfall is currently greater than 500 mm per year, recharge occurs in most years. Even if rainfall was to fall dramatically (e.g. by 20%), there should still be sufficient recharge to meet the modest requirements of hand pump-based domestic supply. However, prolonged droughts have caused widespread source failures in the past, and greater rainfall variability increases the need for better drought early warning and response (see below).

Groundwater access and use

As rainfall and surface water sources become less reliable, demand for groundwater is likely to increase. This pattern can already be observed across seasons, and between normal and drought years. Research in Ghana, Malawi, South Africa and Ethiopia (Calow et al., 1997; MacDonald and Calow, 2007) sheds some light on the relationships between water availability, access and use, and the causes of source failure.

During a prolonged dry season or drought, surface water and unimproved groundwater sources (shallow wells and small springs) can fail, leaving only those water points drawing from larger groundwater bodies operational. Hence larger springs, deep hand-dug-wells and boreholes can provide reliable access to water across seasons, while surface water bodies and unimproved sources become increasingly unreliable. That said, even reliable sources can fail during a drought, though precise causes are not always obvious.

First, prolonged pumping throughout the day can put considerable strain on the pump mechanism leading to breakdowns. This is exacerbated if water-levels in boreholes are falling and pumping lifts are increasing. If maintenance is neglected – for example when emergency drilling is prioritised over repair and rehabilitation during a drought – the source will fail even if water is still available at depth.

Second, water levels may fall in the immediate vicinity of a well or borehole, or group of sources. This is most likely to occur where high demands on a groundwater

source are combined with low aquifer permeability and storage (Wright, 1992; MacDonald et al., 2008b). However, if the well is allowed to recover, supply can be restored, hence people may begin collecting water at night when demand falls and water levels rebound. In both cases – mechanical failure and source-specific drawdown – the key problem is accessing available water rather than its absolute availability.

Irrigation incentives

Many of the impacts of climate change described in the IPPC Fourth Assessment Report (Boko et al 2007) relate to agriculture. The report presents a bleak picture for developing countries – and Africa in particular – with projections that rainfed cereal yields will be reduced in some areas by up to 50% by 2050. Rising food prices have already raised concerns about impacts on poor people, and whether food production from rainfed systems can be increased within the constraints imposed by land and water.

In this context, expanding irrigation seems an obvious way forward. A key question is whether groundwater-based irrigation could provide a sustainable basis for reducing poverty and building climate resilience – whether promoted by government or developed autonomously by local people. There are no simple answers, given the variety of contexts involved, and certainly no ‘one size fits all’ approach for improving livelihoods (IFAD, 2008). The recent Comprehensive Assessment Report (Molden, 2007) argues strongly for an emphasis on smallholder irrigation, but groundwater development needs to be carefully managed (MacDonald et al., 2009). In the lower yielding, more complex hydrogeological environments that underlie much of sub-Saharan Africa (SSA), over-exploitation may not be the major concern: such aquifers are to some extent self regulating, as drawdowns in individual boreholes increase substantially under load. However, additional water withdrawals from dedicated irrigation wells or multi-purpose sources could increase local competition between uses and users.

The groundwater resources most at risk from over-exploitation are arguably those in the (more limited) higher yielding aquifers such as sandstones, unconsolidated sediments and the more productive areas of basement or volcanic rocks. In these environments regional depletion (in contrast to source-specific drawdown) is more likely, particularly where private access and withdrawals rights are strongly entrenched and management thin or absent. Hence in areas of North Africa, where groundwater development supports roughly 30% of agricultural production, agriculture is mining non-renewable reserves and nearing the limit of expansion.

Climate change in context

Climate change is receiving growing attention in development debates, and rightly so. However, there is a real danger that other pressures on water resources, and on natural resources more broadly, are being ignored or downplayed.

Separating the impacts of, and responses to, climate change from those related to socio-economic and demographic trends is not straightforward, particularly as autonomous adaptation is driven by all of these factors at the same time. Nonetheless, it is clear that climate change is one of a number of pressures on water resources, and that population growth, urbanisation, land use change and rising food demands will all have a major impact on both patterns and levels of water demand.

Take demographic change as an example. In contrast to the lack of knowledge on the direction and magnitude of hydrological changes under different climate scenarios, the prospects of demographic change in Africa in the 21st Century are known with some certainty. The population of SSA is expected to increase from 700 million in 2007 to 1,100 million in 2030 and 1,500 million in 2050, and it will become increasingly urban. Overall water demand can, therefore, be expected to more than double in the first half of the 21st century, without considering rises in per capita food and water consumption. In Ethiopia, the population is expected to increase from 77 million in 2007 to around 146 million by 2050, an increase of almost 90%. The pressure on land and water this will generate is likely to dwarf the impacts of climate change.

To this we would add that in many of the poorest countries, coping with existing levels of climate variability remains the key challenge (Grey and Sadoff, 2006). In this respect, it is vital that donor perspectives do not lose sight of developing country realities. Perhaps a donor preoccupation with future climate change is obscuring a more balanced appreciation of existing risks and multiple pressures on water resources.

Policy implications

There is a growing body of literature on policy responses to climate change, focusing broadly on prevention (or mitigation) and adaptation. Here we look briefly at adaptation and risk management, focusing on three areas: drinking water access; groundwater-based irrigation; and drought early warning and response. A key contention is that effective intervention in all three areas will require a much better understanding of groundwater conditions, recharge processes and aquifer response to climate variability than exists at present (Calow, 2008).

Extending drinking water access

Increasing access to affordable and sustainable water is central to building household resilience and reducing poverty. Moreover, increasing access to the natural storage provided by groundwater remains critical for buffering climate variability, particularly in SSA where surface water storage is very limited. Calow et al. (in press) identify two key challenges:

- Accelerating groundwater development to meet broad coverage targets, but ensuring that national benchmarking does not obscure failures in reaching the most difficult areas and vulnerable groups. At a local level, for example, water supply projects can gravitate towards favourable areas where water is easier to find and drilling success rates are higher.
- Increasing the reliability of new sources, and addressing the under-performance of existing investments. In many areas, access to water is constrained by preventable problems: pumps break down because inappropriate technologies have been used, or communities receive little training in basic maintenance; water points dry up even though groundwater is locally available; and groundwater investment is ad hoc and uninformed because there are no data or maps to guide development.

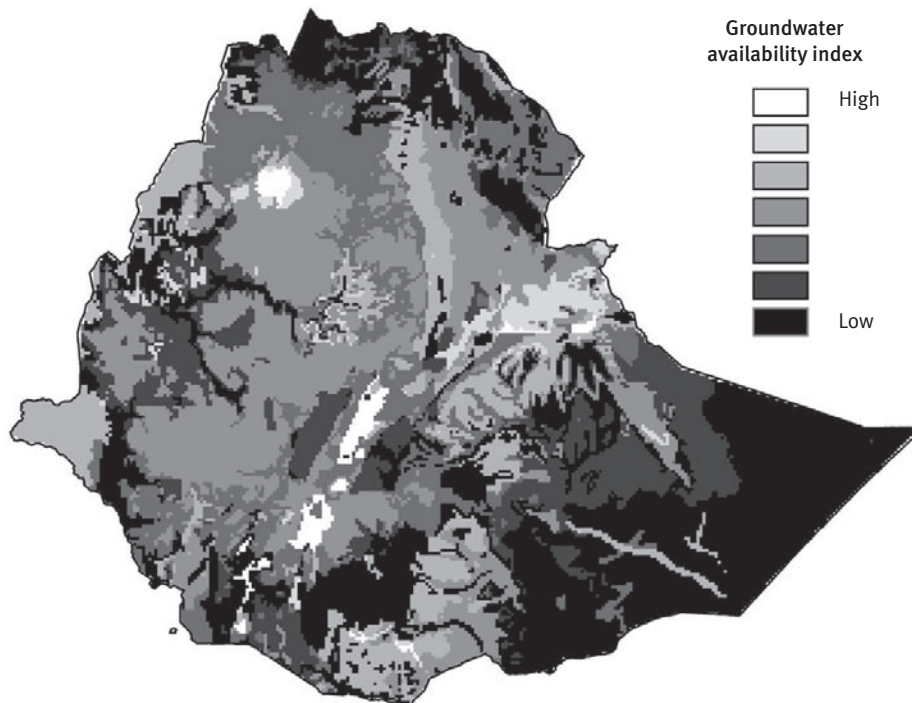
Irrigation development

Developing groundwater for smallholder irrigation holds promise for strengthening livelihoods and improving food security (Molden, 2007), and a comparison with the widespread use of groundwater for irrigation in Asia suggests room for growth (Foster et al., 2008). However, the groundwater boom experienced in parts of Asia was made possible through infrastructure development, access to cheap energy, easy credit and market integration – factors that catalysed massive private investment. In many areas of SSA, these prerequisites are missing, and putting them in place will be a difficult and long term endeavour.

There are other differences between SSA and Asia that should lead to a more sober assessment of irrigation potential. For example, hydrological and hydrogeological settings in SSA and Asia are different. Low permeability aquifers with limited storage account for around 80% of Africa's land area, so that while they are adequate for domestic use and small-scale, supplemental irrigation, they cannot support the kind of intensive development that has emerged over large areas of India, Bangladesh or northern China.

So where does this leave us? There is a clear need for better information on resource conditions and trends, recognising that groundwater has the potential to provide limited irrigation across wide areas of SSA,

Figure 3: Map of groundwater availability during drought for Ethiopia



Source: Adapted from MacDonald et al. (2001).

but that ad hoc development could threaten domestic supplies and put aquifers under stress, particularly in those areas where supply and demand is already finely balanced. The economic benefits from low volume, multi-purpose systems serving domestic, livestock, irrigation and other users make this type option attractive, but questions remain over how such systems are financed and managed by different user constituencies, and whether benefits accrue to the most vulnerable (Adank et al., 2008).

Drought warning and response

The impact of drought on food security in Africa has received a great deal of attention over the last 30 years. One outcome is the establishment of numerous early warning systems. These have become increasingly sophisticated but major deficiencies remain, particularly in relation to their narrow focus on food. Calow et al. (in press) describe how repeated calls for a more balanced approach to drought planning and response, focusing on wider public health needs (including water and sanitation), have been ignored.

What would a more ‘balanced’ approach look like? Calow et al. (ibid) suggest a two-pronged approach to drought planning and response, combining water mapping with livelihoods monitoring:

- *Water mapping – identifying vulnerable areas.* Maps can be used to highlight those areas likely to be worst affected by changes in water availability during drought. Figure 3 shows an example for Ethiopia, combining data on rainfall, geology and hydrogeology to identify zones of varying groundwater development potential and drought reliability. Prepared, ideally, at regional and sub-regional levels, such maps can highlight critical monitoring areas and help target drought-proofing measures (e.g. rehabilitation of water supply infrastructure and well deepening).
- *Livelihoods monitoring – responding to local needs.* To identify the most vulnerable areas and groups, local information is needed on both water and food security. From a water security perspective, indicators include incidence of disease and ill-health, rationing of basic water needs, time taken to collect water, the distress use of poor quality sources for potable needs, conflict over water and distress migration. Combining these data with indicators of food insecurity can then provide a clearer picture of livelihood security and the interventions needed to support it. Interventions may include pump repair and maintenance in the early stages of drought, or assistance with water transport and tankering in the later stages.

Conclusions and research needs

There is a re-emerging consensus that water resources development and management are essential to generate wealth, alleviate poverty and mitigate climate risk (Grey and Sadoff, 2006). This Background Note has highlighted the role groundwater plays in meeting these objectives. We note that further development is essential, but a much sharper appreciation of aquifer responses to changing climate, storage limits and demand pressures is needed if this development is to be sustainable. We offer the following broad conclusions:

1. Rural water supplies in Africa are overwhelmingly dependent on groundwater, and dependence is likely to increase. A key advantage of groundwater-based supply is reliability, both for domestic and productive uses.
2. Climate modelling uncertainties, combined with rapid socio-economic change, make predicting water futures very difficult. Downscaling problems are unlikely to be resolved in the short to medium term, if at all. While there is good confidence in temperature projections, rainfall scenarios remain much more uncertain, as do impacts on groundwater recharge. Demand-side pressures on water resources are more clear cut, and may dwarf the impacts of climate change.
3. Is there a problem? Yes, but it is important to emphasise that climate change will not lead to the continent-wide failure of rural water sources. This is because groundwater-based domestic supply requires very little recharge. However, a significant minority of people – as many as 90 million – could be affected if rainfall declines significantly in those areas with limited groundwater storage, especially if the frequency of droughts increases.
4. In most areas, the key determinants of water security will continue to be access rather than availability related. Extending access, and ensuring that targeting and technology decisions are informed by an understanding of groundwater conditions, will become increasingly important. A key contention is that sustainable development requires a much better understanding of groundwater conditions, recharge processes and aquifer responses to climate variability than exists at present.
5. Accelerating groundwater development for irrigation could increase food production, raise farm incomes and reduce vulnerability. However, ad hoc development could threaten domestic supplies and, in some areas, lead to groundwater depletion. Comparisons between irrigation development in Asia and irrigation potential in SSA should be treated with caution.
6. The prevailing ‘food-first’ culture that dominates vulnerability assessment and emergency response in most African countries ignores the impact of water insecurity on livelihoods, and the role water interventions can play in reducing immediate and longer term vulnerability. There is a pressing need to broaden assessment and response systems to include non-food needs and monitoring data on water availability, access and use.

For further information, please contact Roger Calow, Programme Leader, ODI Water Policy Programme (r.calow@odi.org.uk).

References

- Adank, M., Jeths, M., Belete, B., Chaka, S., Lema, Z., Tamiru, D. and Abebe, Z. (2008) *The costs and benefits of multiple uses of water: the case of Gorogutu woreda of East Hararghe zone, Oromiya Regional States, eastern Ethiopia*. RiPPLE Working Paper 7 (<http://www.rippleethiopia.org/documents/>)
- Boko, M., Niang, I., Nyong, A., Vogel, C., Githeko, A., Medany, M., Osman-Elasha, B., Tabo, R. and Yanda, P. (2007) 'Africa' in M. L. Parry, O. F. Canziani, J. P. Palutikof, P. J. van der Linden and C. E. Hanson (eds), *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge: Cambridge University Press.
- Calow, R. C., Robins, N. S., MacDonald, A. M., Macdonald, D. M. J., Gibbs, B. R., Orpen, W. R. G., Mtembezeka, P., Andrews, A. J. and Appiah, S. O. (1997) 'Groundwater management in drought prone areas of Africa', *International Journal of Water Resources Development* 13: 241-261.
- Calow, R. C. (2008) 'Future directions in water and sanitation'. ODI Opinion, October (www.odi.org/wpp).
- Calow, R. C., MacDonald, A. M., Nicol, A. L. and Robins, N. S. (in press) 'Groundwater and drought in Africa', *Ground Water*.
- Carter, R. C. and Alkali, A. G. (1996) 'Shallow groundwater in the northeast arid zone of Nigeria', *Quarterly Journal of Engineering Geology* 29: 341-356.
- Christensen, J. H., Hewitson, B., Busuioc, A., Chen, A., Gao, X., Held, I., Jones, R., Kolli, R. K., Kwon, W. T., Laprise, R., Magaña Rueda, V., Mearns, L., Menéndez, C. G., Räisänen, J., Rinke, A., Sarr, A., and Whetton, P. (2007) 'Regional Climate Projections' in S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, M. Tignor & H. L. Miller (eds), *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge: Cambridge University Press.
- Edmunds, W. M. (2008) 'Groundwater in Africa – Palaeowater, climate change and modern recharge' in S. M. A. Adelana and A. M. MacDonald (eds) *Applied groundwater research in Africa*. IAH Selected Papers in Hydrogeology 13. Amsterdam: Taylor and Francis.
- Eilers, V. H. M., Carter, R. C. and Rushton, K. R. (2007) 'A single layer soil water balance model for estimating deep drainage (potential recharge): An application to cropped land in semi-arid North-east Nigeria', *Geoderma* 140: 119-131.
- FAO (2006) *Demand for irrigated products in sub-Saharan Africa*. Water Report No. 31. Rome: FAO.
- Foster, S. S. D., Tuinhof, A. and Garduño, H. (2008) 'Groundwater in Sub-Saharan Africa – A strategic overview of developmental issues' in S. M. A. Adelana & A. M. MacDonald (eds) *Applied groundwater research in Africa*. IAH Selected Papers in Hydrogeology 13. Amsterdam: Taylor and Francis.
- Giordano, M. (2005) 'Agricultural groundwater use and rural livelihoods in sub-Saharan Africa: a first-cut assessment', *Hydrogeology Journal* 14: 310-318.
- Grey, D. and Sadoff, C. W. (2006) 'Water for Growth and Development' in *Thematic Documents of the IV World Water Forum*. Mexico City: Comisión Nacional del Agua.
- Hulme M., Doherty R., Ngara T., Mew M. and Lister D. (2000). African climate change 1900 - 2000. Climate Research, 17: 145-168. Inter-Research, Germany.
- IFAD (2008). Water and the Rural Poor: Interventions for Improving Livelihoods in Sub-Saharan Africa. FAO Land and Water Division, Rome, 2008.
- JMP (2008) *Global water supply and sanitation 2008 report*. Joint Monitoring Programme WHO/UNICEF. Geneva: World Health Organization.
- Macdonald, A. M., Calow, R., Nicol, A. L., Hope, B., Robins, N. S. (2001) Ethiopia: Water Security and Drought, *British Geological Survey Technical Report WC/01/02*.
- MacDonald, A. M., Davies, J., Calow, R. C. and Chilton, J. (2005) *Developing groundwater: a guide for rural water supply*. Rugby: ITDG Publishing.
- MacDonald, A. M. and Calow, R. C. (2007) 'Drought and community water supplies', *Waterlines* 26 (1): 14 -16.
- MacDonald, A. M., Davies, J. and Calow, R. C. (2008a) 'African hydrogeology and rural water supply' in S. M. A. Adelana & A. M. MacDonald (eds), *Applied Groundwater Studies in Africa*. IAH Selected Papers in Hydrogeology 13. Amsterdam: Taylor and Francis.
- MacDonald, A. M., Barker, J. A. and Davies, J. (2008b) 'The bailer test: a short effect pumping test to assess borehole success', *Hydrogeology Journal* 16: 1065-1075.
- MacDonald, A. M., Calow, R. C., MacDonald, D. M. J., Darling, W. G. and Dochartaigh, Ó. (in press) 'What impact will climate change have on rural water supplies in Africa?', *Hydrological Sciences Journal*.
- Molden, D. (ed.) (2007) *Water for food, water for life. A comprehensive assessment of water management in agriculture*. London: Earthscan and Colombo: IWMI.
- New, M., Hulme, M. and Jones, P. D. (1999) 'Representing twentieth century space-time climate variability. Part 1: development of a 1951-90 mean monthly terrestrial climatology', *Journal of Climate* 12: 829-856.
- Wright, E. P. (1992) 'The hydrogeology of crystalline basement aquifers in Africa' in E. P. Wright and W. Burgess (eds), *The hydrogeology of crystalline basement aquifers in Africa*. Geological Society London Special Publications 66.



The Overseas Development Institute is the UK's leading independent think tank on international development and humanitarian issues. ODI Background Notes provide a summary or snapshot of an issue or of an area of ODI work in progress. This and other ODI Background Notes are available at www.odi.org.uk