Drought Mitigation in Semi-Arid Africa: The Potential of Small-Scale Groundwater Irrigation

Maura Allaire
Resources for the Future
International Water Management Institute

Abstract
This policy paper discusses the potential of small-scale groundwater irrigation to mitigate the effects of drought in semi-arid, sub-Saharan Africa (SSA). About 16 percent of the population in SSA lives in semi-arid areas *(1)*. The majority of the population in semi-arid areas is dependent on subsistence farming that is characterized by susceptibility to drought, poor access to markets, and food insecurity. Groundwater irrigation is currently an underutilized resource that could mitigate the effects of drought, such as surface water scarcity and crop failure. Groundwater supplies are less prone to drought than surface water and thus could provide a more reliable source of agricultural water. A major hurdle for small-scale groundwater irrigation in SSA is overcoming economic water scarcity. Strategies for promoting groundwater irrigation in a sustainable manner, such as farmer management of irrigation systems, are outlined.

Maura Allaire
maura.allaire@gmail.com

Drought in Semi-Arid Sub-Saharan Africa

Drought events resulting in crop failure and vulnerable livelihoods occur regularly in semi-arid sub-Saharan Africa (SSA). In Niger, severe drought resulted in a famine during 2005 that caused food insecurity for 2.5 million people *(2)*. The impacts of drought last beyond one growing season, since crop failure means a lack of seeds to plant for the following growing season. Droughts have especially affected the Sahel region of West Africa, which is a semi-arid region stretching from Senegal to Sudan. Mean drought duration and drought spatial extent have increased in the Sahel from 1950 to 2000 *(3)*. A long-term drought from the 1960s to the 1980s affected food production in the Sahel, but there has been an upward trend in West African rainfall since the 1990s *(4)*. Sea surface temperature changes were the main cause of this long-term drought *(5)*, with changes in land-use also playing a role *(6)*. Increased greenhouse gas levels are believed to be responsible for the recent upward trend in rainfall *(7)*.

The outlook for future droughts and climate trends highlights the importance of future access to water, especially in areas that currently rely on rainfall or surface water irrigation for agriculture. By 2050, rainfall in SSA could drop by 10%, leading to major water shortages *(8)*. A general decrease in annual rainfall is predicted to significantly affect access to surface water across 25% of Africa by 2100 *(9)*. In the wetter, southern areas of the Sahel a 10% decrease in rainfall would reduce drainage by 17%, while in the drier, northern areas such a decrease could decrease surface drainage by 50% *(9)*. However, uncertainty exists in climate forecasting. Other forecasts predict enhanced rainy season precipitation in West Africa at the end of the century *(10)*.

Groundwater Irrigation and Drought Mitigation

There is evidence of a direct correlation between drought susceptibility and a lack of investment in drought preparedness and water storage *(11)*. Making subsistence agriculture more resistant to drought offers greater livelihood stability as opposed to emergency food provision to mitigate crop failure. Groundwater irrigation offers potential to mitigate the effects of drought and erratic rainfall on agricultural production. Groundwater supplies are less prone to drought than surface water since groundwater levels are less correlated with rainfall. Better resistance to drought and changes in rainfall is a valuable characteristic since temporal rainfall variability in SSA is among the highest in the world *(12)*.

Increasing agricultural productivity with groundwater irrigation, and lessening reliance on surface water sources, can reduce the impacts of predicted declines in rainfall. In East Africa, continuing on a business- as-usual scenario is estimated to result in a 50 % increase in the undernourished population. However, even modest increases in agricultural capacity could reduce undernourishment by 40 % *(13)*. Agricultural production growth can be achieved where agricultural water can be developed cheaply and markets can be developed *(1*). However, in SSA, there has been little gain in productivity due to technology. As population grows faster than food production, food self-sufficiency has declined *(1)*.

Benefits of Small-Scale Groundwater Irrigation

Small-scale groundwater irrigation offers the potential to mitigate the effects of drought by improving food security and alleviating poverty. Groundwater irrigation can increase agricultural production at relatively low-cost and benefit many more small farmers than reservoir irrigation systems. Groundwater irrigation can also lessen crop failure due to drought since groundwater is often less vulnerable to drought than surface water sources such as streams, lakes, and reservoirs *(14)*. Groundwater is typically the only perennial source of water supply in semi-arid areas and groundwater aquifers can continue to yield water during a dry year even when surface water bodies dry up. With expected changes in rainfall patterns due to climate change, groundwater offers a more reliable source of water than surface water bodies, assuming proper management.

Small-scale irrigation systems are defined by the Food and Agriculture Organization as being controlled by single farmers or farmers' groups and are usually less than 100 hectares (ha) *(15)*. Many development organizations believe small-scale irrigation methods are an effective way to increase food production *(16)*. In the 1980s, small-scale irrigation gained favor after disappointing results of costly irrigation investments in larger, government-controlled surface irrigation schemes in the 1970s and 1980s *(17)*. The Commission for Africa has described the need to invest in doubling the irrigated area in SSA, from 6.4million ha in 2000 to 12.8 million ha in 2050, in order to achieve the Millennium Development Goals *(18)*. Governments and donors should focus on relatively inexpensive, small-scale methods for irrigating often widely scattered plots of land *(19)*. Examples of small-scale groundwater irrigation methods are depicted in Figure 1.

Figure 1. Examples of small-scale groundwater irrigation methods

Left Photograph: Shallow groundwater irrigation using hand pump *(20)*

Right Photograph: Traditional groundwater irrigation in Ghana *(author's photograph)*

Benefits of small-scale groundwater irrigation include:

1. Availability: Groundwater is available almost everywhere and thus allows for decentralized management *(21)*.
2. Immediacy: Groundwater irrigation can be developed quickly by individual farmers or small groups, unlike large surface irrigation structures, which might require government participation or a large cooperative effort *(21)*.
3. Low-Cost: Capital costs of groundwater structures are much lower per area of irrigation than those of surface structures since reservoir construction is not required and water sources can usually be developed close to the demand *(22)*. However, operating costs tend to be higher for groundwater irrigation schemes *(21)*.
4. Drought Resistant: Groundwater is typically less vulnerable to drought than surface water sources since groundwater has a lagged response to changes in rainfall and faces fewer losses of water to evaporation.
5. Farmer-Managed: Since small-scale groundwater irrigation tends to be farmer-managed rather than controlled by the government or a commercial agency, farmers can directly decide how much to irrigate and maintain their own equipment.
6. Benefits Many Farmers: In SSA, poverty incidence is lower in irrigated farming than in other farming systems *(19)* and groundwater irrigation promotes greater gender, class, and spatial equity than large surface irrigation *(21)*. Many more small farmers can benefit from small, spatially dispersed groundwater irrigation systems than reservoirs, since only a limited number of plots can be downstream of a reservoir.

7. On-Demand: Groundwater provides on demand irrigation, which provides farmers freedom to apply water when their crops need it the most *(21)*.
8. Fewer Losses: Transport and storage losses are lower for groundwater than surface irrigation. Improved reliability of water supply can encourage farmers to invest in improving other agricultural inputs such as seeds, cultivation practices and nitrogen fertilizers *(21)*.

Groundwater Irrigation Issues

While groundwater resources offer large potential for irrigation, over-exploitation of these resources can have severe consequences. Groundwater depletion, well interference, and water quality must be taken into consideration when developing and managing groundwater resources. Sustainable management is essential in order to avoid artificially inflating food production only to deplete aquifers and cause agricultural output to rapidly decline.

Uncontrolled groundwater abstraction can cause water tables to fall to levels that could require significant time to recharge. India is a prime example of over-pumping leading to groundwater depletion. Groundwater irrigation became widespread in India in the 1960s and 1970s. Groundwater now supplies almost 60% of irrigated area in India *(23)*. Some states use groundwater resources more intensely than others, as evidenced by drastically declining water tables in some areas. In the state of Harayana, average water table depth falls by 1-33 cm each year *(23)*. Since groundwater tends to be a domestic water supply source as well as an irrigation source, entire communities risk depleting their drinking water supply if groundwater levels drop below the bottoms of wells. In India, field studies have shown how excessive pumping by a few farmers can cause villages to be dependent on external sources for drinking water *(23)*. The quality of groundwater available for drinking can also be affected by excessive use. As water tables fall, people must drill deeper for water, sometimes drilling into deep aquifers that can contain harmful trace minerals such as arsenic and fluoride. In India, there have been health problems related to arsenic and fluoride. Declines in aquifer levels also interrupt surface-groundwater hydrologic connections and cause streams that were formerly fed by groundwater to become dry.

However, semi-arid SSA faces less risk of extreme groundwater depletion than India since there is a much lower population density, farms are dispersed, and large-scale agriculture is not driving groundwater development. Furthermore, most rural irrigation schemes in SSA promote simple technologies with limited pumping rates and the mostly hard rock aquifers prevent larger scale development *(24)*. With an estimated increase in irrigated land of 1.9% per year from 1990-2010, and decreasing growth rates thereafter, irrigated areas in SSA are not expected to exceed the estimated current irrigation potential *(25)*.

Over-extraction of groundwater can affect water quality and make it unsuitable for agricultural use. Excessive irrigation can cause fields to become water-logged, which results in saline and alkaline soil. In India, more than 15% of irrigated land cannot be cultivated due to salinity and alkalinity *(26)*. Additionally, agricultural chemicals and salts, such as chloride and nitrate, can leach to shallow groundwater and cause it to be unusable for irrigation or domestic use *(14)*.

Potential of Groundwater Resources in Sub-Saharan Africa

SSA contains substantial groundwater resources. In fact, per capita, SSA has greater groundwater supplies than Europe or Asia, including India and China, two of the world's largest groundwater irrigation users *(27)*. Renewable groundwater supplies in SSA are estimated to be 1,500 km3 per year *(28)*, compared to 800 km3 per year in China and 400 km3 per year in India. Groundwater availability per capita in SSA is three times the availability of China and six times that of India. However, other measures suggest not so plentiful water resources in Africa. The ratio of runoff to precipitation for all of Africa is 0.20, about half the global mean of 0.35 *(24)*. This estimate includes North Africa, however, which is an extreme in terms of water resource scarcity. Other areas that are water scarce include Sudan, Uganda, South Africa, and northwest Ethiopia *(19)*. Excluding North Africa, SSA as a whole is not water poor since the region contains with 18% of global land area, 9% of the world's water resources, and about 11% of the world's population *(28)*.

While most areas of SSA do not face physical water scarcity, many areas do confront economic water scarcity. Economic water scarcity occurs when physical water resources are available, but there is a lack of economic resources and incentives to develop water resources *(29)*. Giordano (2005) states, "If there is a groundwater problem in SSA, it seems generally to be one of underdevelopment".

SSA generally has substantial groundwater supplies, but the value of these supplies is reduced due to unequal distribution that is determined by geology and rainfall. Much of the supply is deep underground or located within hard rocks, which require costly drilling to reach *(12)*. Furthermore, groundwater supplies tend to be greatest in areas of high rainfall, which do not stand to gain significantly from groundwater irrigation. Over half of annually renewable groundwater supplies are located within four countries, the Democratic Republic of Congo, The Republic of Congo, Cameroon and Nigeria *(12)*.

Groundwater availability is primarily a function of geology. Groundwater is stored within fractures and holes in rocks. The more interconnected these fractures and holes are, the more easily water can flow through, and the rocks are defined as having a greater amount of permeability. Groundwater is supplied by rainfall through a process called recharge which involves rain water and surface water infiltrating into the soil and travelling downward towards the water table. Groundwater recharge is dependent on a number of factors, including total annual rainfall, distribution and intensity of rainfall events, connection to streams and rivers, soil type, and land use *(24)*. The amount of recharge determines the amount of groundwater that can be withdrawn sustainably. The most common rock that stores water in SSA is crystalline basement rock. It underlies 40% of the land area in SSA and a rural population of 220 million lives within its boundaries. Groundwater is found in fractures and the top few meters of weathered rock. Borehole and well yields are generally low, but can be sufficient for rural domestic supply and livestock *(22)*.

Potential of Groundwater Irrigation in Sub-Saharan Africa

Groundwater is an underutilized resource in SSA. Groundwater has long been used for agricultural purposes in SSA, but total usage remains low *(12)*. Withdrawals of groundwater as a percent of renewable supplies average less than 2% in SSA *(30)*. Only 1–5 % of cultivable land in SSA is irrigated, compared to the 30–35 % in Asia *(29)* and a global average of 17-20% *(31)*. Groundwater is estimated to irrigate about 0.3 to 0.8% of cultivable land in SSA *(28), (12)*. The FAO estimates that the available water and land resources in SSA could allow for an eight-fold increase in irrigated area, resulting in 42.5 million ha of irrigated land *(29)*. Groundwater could represent a large portion of supplies for new irrigation since only 10% of the irrigated area in SSA is served by groundwater *(21)*. Groundwater in SSA offers a significant potential to lessen the effects of surface water scarcity due to generally short, highly variable, and unpredictable rainy seasons in semi-arid SSA *(29)*.

Despite the potential of groundwater irrigation in SSA, expansion of irrigation has been the slowest in the world. Over the past 40 years, 4 million hectares of new irrigation has been developed in SSA, compared to 25 million hectares in China and 32 million hectares in India *(28)*. Agricultural output has not kept pace with population growth *(28)* and productivity is the lowest in the world, with per capita output 56 percent of the world average *(32)*. Increases in output have occurred mostly due to expansion of crop land rather than increases in productivity. Over 80 percent of increased output since 1980 is due to expansion of crop land compared to less than 20 percent for all other regions *(1)*.

Reasons for Low Utilization of Groundwater Irrigation

Low usage of and investment in groundwater irrigation could be due to high cost of well installation in SSA, low-yielding groundwater sources in some areas, and the extent of rainfed agriculture. Groundwater development in SSA is hindered by the relatively high cost of well construction compared to India and China. Costs of more than US$ 5,000-15,000 per well are widely reported *(11)*. Costs are relatively high because of a shortage of private companies in SSA providing well construction, pump supply, and pump maintenance services. While pump manufacturing facilities and well construction companies rapidly grew in China and India during the 1970s and 1980s, a large private market for groundwater equipment and services has not developed in SSA. Furthermore, costs are elevated in SSA due to corruption in issuing drilling contracts and inappropriate well design *(11)*.

Estimating the potential for groundwater irrigation is challenging because current levels of groundwater irrigation are not well-known. There is little information, of varying quality for both groundwater resources and groundwater use for many areas in SSA. Groundwater irrigation is often small-scale and informal, which causes it to be overlooked by many African governments and development agencies. Published studies tend to focus on government-funded irrigation schemes *(12)*. Poor documentation of irrigated areas contributes to an underestimation of agricultural groundwater use *(12)*.

While little documentation exists about the extent of groundwater irrigation in SSA, groundwater has traditionally been used in agriculture in a number of areas. In many areas, traditional groundwater abstraction systems are now being replaced by modern technologies including diesel and electric pumps *(12)*. For example, in northern Nigeria during the late 1970s and

1980s, small diesel pumps were introduced in large numbers for dry season irrigation. These motor pumps were attractive due to their convenience and their ability to increase productivity. The motor pumps largely replaced traditional systems due to subsidized wells and pumps, the establishment of supply outlets for affordable spare parts, and low fuel costs at the time *(14)*. In many parts of SSA groundwater is not yet used for agriculture and in other areas it has been used for long periods. Where it makes economic sense, farmers quickly adopt groundwater use. Crops grown under small-scale irrigation, which may use a large share of groundwater, tend to be traditional crops such as sorghum, millet, or horticulture *(12)*.

Recommendations for Sustainable Groundwater Resource Management

To encourage groundwater irrigation in semi-arid SSA and to ensure sustainable groundwater use, the following recommendations are offered.

1. Small Farmer Management of Irrigation Systems

   The most profitable and sustainable irrigation schemes are those where small farmers are able to take over operation and maintenance after construction *(1)*. In addition, farmer involvement improves irrigation design and reduces costs *(1)*. Globally, irrigation management responsibilities and rights are being transferred to farmers *(29)*. Farmer management can increase the equitable use of resources. This management style is most effective when farmers own relatively homogenous plots of land *(23)*. A participatory approach is important in rule-making and legislation because perceptions about who designs the rules play a large role in determining compliance. Compliance tends to be low when it is perceived that rules were designed by the local elite and especially low when designed by government officials *(23)*.

2. Groundwater Monitoring

   Monitoring groundwater supplies is essential to determining sustainable groundwater use and assessing the status of rural water supplies. In addition to effective groundwater management, monitoring allows for drought prediction. While governments and donors often give low priority to monitoring and assessment activities, such efforts can reduce the need for costly emergency interventions for droughts. Research is needed to determine how cost-effective and reliable monitoring networks can be established and maintained *(24)*. Also, monitoring responsibilities for data collection and analysis need to be clearly defined. Monitoring does not necessarily need to be conducted by the government. In Ghana and Malawi, many of the operational tasks traditionally carried out by government are being turned over to local communities *(24)*. Small farmers could keep daily records of pumping rate, pumping duration, and groundwater levels *(14)*. However, training and accuracy might be an issue.

   Once monitoring data is collected, there should be a centralized information office so that a complete assessment of national groundwater resources can be conducted. Often, the information situation is exacerbated by the fact that data holdings which do exist are dispersed amongst a range of different organizations (government, NGOs, consultants) at national, regional, and local levels. In South Africa, efforts are being made to develop a National Water Supply and Sanitation Management Information System. *(24)*.

3. Further Research to Evaluate Extent of Resources and Vulnerability to Drought

   More research is needed to assess SSA groundwater resources and areas where groundwater irrigation is appropriate. Aquifer properties and recharge rates must be assessed to ensure sustainable groundwater use, and shallow aquifers should be evaluated to determine appropriateness for small-scale groundwater irrigation. Additional research is needed to improve understanding of SSA's current agricultural groundwater use, especially to understand where additional development is possible.

   Further research is also needed to determine areas vulnerability to drought. Vulnerability to groundwater drought is determined by population density, well coverage, aquifer characteristics and groundwater recharge. Assessing an area's vulnerability to drought can ensure appropriate well design and technical choices. In areas where communities, and not a central government, make decisions, a range of water supply options could be modified to ensure that the options are appropriate to local groundwater conditions *(24)*.

4. Conduct Monitoring and Development of Groundwater Simultaneously

   Conducting hydrological observations, policy formulation, and irrigation development at the same time allows for urgent needs of the rural population to be met while determining sustainable use and management of groundwater resources. Development of wells allows groundwater observations to be made, and then these observations allow for modeling. Modeling, in turn, which allows for the development of policy to manage groundwater resources sustainably. Often there is conflict between conducting thorough research that leads to policy development and the urgency of poverty alleviation *(14)*. Concurrent monitoring and development of groundwater permits a middle solution.

5. Subsidize Well Construction and Pumps

   Most areas in SSA do not lack water resources, but rather the financial means to develop water sources for agriculture. Small farmers in areas vulnerable to drought should be supported with subsidies to develop groundwater for agricultural use and to mitigate the effects of drought. Groundwater irrigation in northern Nigeria was successfully introduced in the 1980s due to subsidized wells and pumps, as well as the establishment of supply outlets for affordable spare parts. Subsidies in the form of loans for private groundwater irrigation can be a major tool for poverty reduction *(33)*. While small farmers should use their own income and labor to develop groundwater supplies, government or development agencies should support technology development and spread technological skills *(29)*.

.

6. Select Low-Cost, Easily Repairable Equipment

   Low cost drilling and pumping technologies that feature equipment that is easy to repair and maintain are best suited for groundwater irrigation development in SSA. Ease of repair and locally-available parts helps decrease the likelihood that equipment will be abandoned. Capital costs as well as operating costs and availability must be taken into consideration. Small, portable drilling rigs could offer potential due to low capital cost. Likewise, traditional water abstraction devices could be used at relatively low cost. While electric pumps aren't feasible in SSA due to a lack of electricity in rural areas, diesel pumps could offer potential, assuming low fuel costs.

Pump technology limitations can offer a method of controlling groundwater abstractions. The rate of abstraction can be limited by well diameter, suction limit, depth, and choice of non-motorized versus motorized pump. For example, diesel pumps that are popular in northern Nigeria can only be used for shallow groundwater (6-7m); thus providing a limit to over-pumping. Rather than relying on water rights permitting, governments could set limits on allowed technology.

Conclusion

Small-scale groundwater irrigation offers significant potential to mitigate the effects of drought and erratic rainfall on agricultural production in semi-arid, sub-Saharan Africa. Groundwater supplies are less prone to drought than surface water since groundwater levels are less correlated with rainfall. Past evaluations suggest that the potential of groundwater resources in sub-Saharan Africa is significant. Groundwater availability per capita in sub-Saharan Africa is estimated to be three times the availability of China and six times that of India. A major hurdle to expansion of groundwater irrigation in sub-Saharan Africa is economic water scarcity. While physical water resources are available, there is currently a lack of economic resources and incentives to develop water sources. Strategies for promoting groundwater irrigation in a sustainable manner include farmer management of irrigation systems, concurrent groundwater monitoring and development, and subsidies for well construction and pumps.

REFERENCES

(1) World Bank. 2008. Investment in agricultural water for poverty reduction and economic growth in Sub-Saharan Africa. www.fanrpan.org/documents/d00508/

(2) United Nations World Food Program. 2005. “WFP’s Niger appeal triples to help 2.5million people facing extreme hunger”. www.wfp.org/english/?moduleid=137&key=1355.

(3) Sheffield, Justin and Eric Wood. 2008. Global Trends and Variability in Soil Moisture and Drought Characteristics, 1950–2000, from Observation-Driven Simulations of the Terrestrial Hydrologic Cycle. *Journal of Climate*. 21(3):432–458.

(4) Nicholson S, Some B, Kone B. 2000. An Analysis of Recent Rainfall Conditions in West Africa, Including the Rainy Season of the 1997 El Nino and the 1998 La Nina Years. *Journal of Climate*. 13(14):2628–2640.

(5) Rowell, David. 2003. The Impact of Mediterranean SSTs on the Sahelian Rainfall Season. *Journal of Climate*. 16(5):849–861.

(6) Xue, Y. 1997. Biosphere Feedback on Regional Climate in Tropical North Africa. *Q J R Meteor Soc.* 123:1483–1515.

(7) Paeth H, Hense A. 2004. SST Versus Climate Change Signals in West African Rainfall: 20th-Century Variations and Future Projections. *Climate Change* 65:179–208.

(8) Nyong, A. 2005. *Abstract in* Impacts of Climate Change in the Tropics: The African Experience. Avoiding Dangerous Climate Change. Meterological Office, Exeter, UK. www.stabilisation2005.com

(9) de Wit, M. and Stankiewicz, J. 2006. Changes in Surface Water Supply Across Africa with Predicted Climate Change. *Science* 31(311): 1917-192.

(10) Maynard K, Royer J-F, and Chauvin F. 2002. Impact of Greenhouse Warming on the West African Summer Monsoon. *Climate Dynamics*. 19:499–514.

(11) World Bank. 2006. Groundwater Development in Sub-Saharan Africa: A Strategic Overview of Key Issues and Major Needs. Case Profile Collection Number 15.

(12) Giordano, Mark. 2005. Agricultural Groundwater Use in sub-Saharan Africa: What do we know and where should we go? Water Policy (7) 613–626.

(13) NASA. 2008. "NASA Data Show Some African Drought Linked to Warmer Indian Ocean". NASA's Goddard Space Flight Center. August 5, 2008

(14) Carter, R.C. and P. Howsan. 1994. Sustainable Use of Groundwater for Small-Scale Irrigation. *Land Use Policy*. 11(4) 275-285.

(15) FAO. 1987. Consultation on Irrigation in Africa. Irrigation and Drainage Paper No 42, FAO. Rome.

(16) International Assessment of Agricultural Knowledge, Science and Technology for Development (IAASTD). 2008. Summary for Decision Makers of the Global Report. www.agassessment.org/docs/IAASTD_GLOBAL_SDM_JAN_2008.pdf

(17) Kay, M. 2001. Smallholder irrigation technology: prospects for sub-Saharan Africa. IPTRID, FAO, Rome. Knowledge Synthesis report, No. 3.

(18) Commission for Africa. 2005. Our Common Interest: Report of the Commission for Africa. www.commissionforafrica.org/english/report

(19) Faures, Jean-Marc, et al. 2007. Reinventing Irrigation. *In* Molden, David (Ed.). Water for Food, Water for Life: A Comprehensive Assessment of Water Management in Agriculture. London, UK: Earthscan; Colombo, Sri Lanka.

(20) van den Berg, Joost. 2008. Exploring shallow groundwater irrigation: current status and future application. MSc Thesis. Delft University of Technology.

(21) Shah, Tushaar; et al. 2007. Groundwater: A global assessment of scale and significance. *In* Molden, David (Ed.). Water for food, water for life: A Comprehensive Assessment of Water Management in Agriculture. London, UK: Earthscan; Colombo, Sri Lanka.

(22) MacDonald, A.M. and Davies J. 2000. A Brief Review of Groundwater for Rural Water Supply in sub-Saharan Africa British Geological Survey. Technical Report WC/00/33

(23) Foster, A. and M. Rosenzweig. 2005. Inequality and the Sustainability of Agricultural Productivity Growth: Groundwater and the Green Revolution in Rural India. India Policy Conference at Stanford University, June 1-3, 2005. scid.stanford.edu/events/India2005/deep2.pdf

(24) Calow, R.C., et al. 1997. Groundwater Management in Drought-prone Areas of Africa. *Water Resources Development.* 13(2)241-261.

(25) FAO. 1997. State of the World's Forests. Series State of the World's Forests. FAO, Rome, Italy. 200 pp.

(26) Vaidyanathan, A. 1994. Second India Studies Revisited: Food, Agriculture and Water Madras Institute of Development Studies, Madras.

(27) Gleick, P. H. 2000. The World's Water 2000–2001. Island Press, Washington DC.

(28) FAO. 2003, FAO AQUASTAT On-line Database.

(29) Van Koppen, B. 2003. Water reform in Sub-Saharan Africa: what is the difference? *Physics and Chemistry of the Earth* 28:1047–1053.

(30) FAO. 2005. Irrigation in Africa in figures: AQUASTAT Survey – 2005. ftp://ftp.fao.org/agl/aglw/docs/wr29_eng.pdf

(31) Bharati, Luna, et al. 2006. Project 65: Shallow Groundwater Irrigation in the White Volta. IWMI Project Description. www.waterandfood.org/research/competitive-call-projects/project-detail/65-shallow-groundwater-irrigation-in-the-white-volta.html

(32) FAO. 2006. Demand for products of irrigated agriculture in sub-Saharan Africa. A regional analysis. Water Report 31. Rome.

(33) IWMI. 2002. "The Socio-ecology of Groundwater in India". Briefing Paper, International Water Management Institute.