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Agricultural groundwater use in sub-Saharan Africa: What do we know and where should we go?

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Abstract

Relatively little is known about agricultural groundwater use and the agricultural groundwater economy of sub-Saharan Africa. However, available evidence suggests that the region's groundwater resources are substantial and greater in per capita terms than in some of the worlds' largest agricultural groundwater users including India and China. Nonetheless, calculations presented here also indicate that the direct contribution of groundwater to sub-Saharan Africa's agricultural economy is small, both in absolute and relative terms. Plausible explanations for low usage include physical geography, economics and economic policies, and politics. In addition to these real factors, incomplete information almost certainly contributes to an underestimation of agricultural groundwater use. Further, it is likely that "traditional" approaches to groundwater valuation inherently miss some of the key groundwater functions in the sub-Saharan African context, in particular as they relate to livestock production and rainfall variability. While this paper supplies a baseline of information in some respects, much additional research is needed to improve our basic understanding of sub-Saharan Africa's agricultural groundwater use and importance, not only to help researchers and policy makers appreciate the value of the region's groundwater resources but also to provide a meaningful knowledge base on which development plans can be built. That said, the ultimate point of applied research should be to understand both where additional development in sub-Saharan Africa is possible and, equally important, where and why it is not.

Keywords: Agriculture; Development; Groundwater; Livestock; sub-Saharan Africa; Water management

1. Introduction

So Geographers in Afric maps
With savage pictures fill the gaps
And o'r uninhabitable downs
Placed elephants for lack of towns

Jonathan Swift

Much of the current research and writing on groundwater economies in the developing world attempts to highlight the resource's major role in recent agricultural growth or the resulting problems of unsustainable withdrawal. However, much of this writing explicitly or implicitly focuses on Asia. While the importance of the groundwater economy of Asia is as real as the threats to its sustainability, there has been a tendency even amongst careful authors to use the Asian example to paint a generalized picture of groundwater in the developing world. Such extrapolation is problematic in that it can misrepresent the true geography of the agricultural groundwater use phenomena and, more importantly from an economic development standpoint, hide location-specific problems and opportunities. Sub-Saharan Africa is a case in point.

Available evidence suggests that sub-Saharan Africa[1] has both substantial groundwater reserves and a long tradition of agricultural groundwater use. Nonetheless, the level of use and the contribution of groundwater to the African agricultural economy appear to be substantially less than in Asia. If there is a groundwater "problem" in sub-Saharan Africa, it seems generally to be one of underdevelopment rather than over abstraction, an unfortunate outcome given the region's rural poverty and the potential poverty-alleviating properties of agricultural groundwater use (Moench, 2003; Shah *et al.*, 2003). That said, there have been few attempts at broad-scale research on the role of groundwater in the agricultural sector of sub-Saharan Africa and even fewer attempts to quantify that role. Thus general statements on the groundwater economy of Africa can only be made with caution. Indeed, we are in as much danger today of "placing elephants" over our knowledge gaps of the sub-Saharan African groundwater economy, much in the way that the cartographers described by Swift above were in filling maps centuries ago. How much groundwater is available? How much is used? What is its contribution to the agricultural economy and rural development? How can we measure such a contribution in the African context? Where are problems of underdevelopment, where is overdevelopment, what are the policies that can solve them? What should be the direction of future research into groundwater development? Most of these questions remain largely unanswered.

Because of the poor state of knowledge on agricultural groundwater use and the groundwater economy within the sub-Saharan Africa setting, the goal of this paper is to develop as full a picture as possible, based on published sources, so as to consolidate known information, highlight critical gaps and inform further research on groundwater and its potential role in solving the region's water and poverty problems. To do this, the paper is divided into three parts. In the first, an overview of the known groundwater resources of sub-Saharan Africa and the state of agricultural groundwater is presented. A typology of agricultural groundwater use in Sub-Saharan Africa is then developed along with rough initial estimates of the magnitude of the existing agricultural groundwater economy. Given that the findings in fact show a relatively small size for the African groundwater economy despite the large resource base, the paper provides a number of hypotheses, including incomplete information, which might answer the question of "why isn't more groundwater used for agriculture in sub-Saharan Africa?" Finally, the paper provides a set of considerations for future analysis of sub-Saharan Africa's groundwater economy and how research might serve to improve both development and conservation of the critical resource.

[1]Sub-Saharan Africa is defined to include all of Africa with the exception of the north African countries of Algeria, Egypt, Libya, Morocco and Tunisia.

2. Groundwater resources and distribution in sub-Saharan Africa

Understanding the general distribution of water resources in sub-Saharan Africa is made difficult by the paucity of available data. As put by the Food and Agriculture Organization of the United Nations (FAO), "The information available is uneven and very poor for some of the African countries" (FAO, 2003b: 51). Nonetheless, it has been estimated that the region, with 18% of global land area, contains some 9% of the world's water resources (FAO, 2003a). Since sub-Saharan Africa has about 11% of the world's population (FAO, 2003a) it cannot, on the whole, be considered water poor by global standards despite common perceptions. In fact, Africa (sub-Saharan and arid North Africa together) has more water available per capita than either Europe or Asia (Gleick, 2000). However, the distribution of water within Africa as a whole is not equal and the continent has the greatest spatial, and perhaps temporal, supply variability of any in the world (Walling, 1996). In general, rainfall is greatest in the Guinea coast and west-central regions and drops, sometimes to desert conditions, as one moves east and away from the equator. This unequal distribution in rainfall is offset to some degree by the prevalence of exotic rivers, such as the Niger, Nile and Okovango, which carry water from wetter to drier regions.

Accessing information on the distribution of groundwater resources in sub-Saharan Africa is, not surprisingly, even more problematic than is the case for total water[2]. Walling puts the problem succinctly, "Detailed information on groundwater and its behavior is lacking for many areas of Africa and it is difficult to provide quantitative assessments of the continent's groundwater resources" (Walling, 1996: 111). Estimates by FAO place sub-Saharan Africa's internally renewable groundwater supplies at around 1,500 km^3 per year (2003a)[3]. This compares with 800 km^3 per year in China and 400 km^3 per year in India, the two nations at the forefront of the boom in groundwater-driven agricultural growth. By these statistics, sub-Saharan Africa as a whole has more than three times the per capita groundwater availability of China and nearly six times the availability of India (see Fig. 1).

Like overall water resources, groundwater resources also have substantial variation within sub-Saharan Africa. According to MacDonald & Davies (2000), groundwater availability is primarily a function of geology. As such, they and others (Foster, 1984; Walling, 1996) divide the region into four general hydrogeologic zones[4]: crystalline basement rock (making up 40% of the region), consolidated sedimentary rock (32%), unconsolidated sediments (22%) and volcanic rock (6%) (MacDonald & Davies, 2000). Crystalline basement rock contains groundwater in the weathered mantle as well as fracture zones. According to Wright (1992), the role of such rock as a general supply source is fairly limited owing low transmissivity. However, it can be a significant source of water for livestock and domestic supply. Consolidated sedimentary rock can hold substantial groundwater reserves, often in artesian conditions and especially in sandstones and limestones which typify older basins (Walling, 1996). However, mudstone areas, which make up some two-thirds of the variety, store little groundwater. Unconsolidated sediments, which typify younger basins, hold groundwater, often in unconstrained conditions within sands and gravels. As MacDonald & Davies (2000) point out,

[2]It is likely that much more hydrogeologic information is actually available than is accessible in the public domain. Likely sources include documents from colonial administrations, technical reports carried by donor agencies and national agencies with responsibility for groundwater development.
[3]Separating groundwater from surface water estimates is complicated because of the interchange between the two systems. FAO separately calculates groundwater, surface water and an adjustment factor to account for the overlap between the two.
[4]Or three zones depending on whether consolidated and unconsolidated sediments are considered as one or two zones.

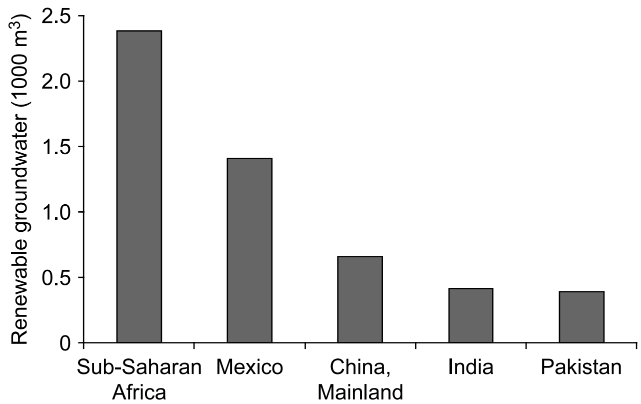

Fig. 1. Annual renewable groundwater supplies, sub-Saharan Africa and selected countries, 1,000 m^3 per person. Source: (FAO, 2003a).

unconsolidated sedimentary rock is often found in river beds and so its groundwater may be especially important for human use because of potential ease of access. However, as Purkey & Vermillion (1995) note, many African river systems tend to be typified by fine and very fine sediments, rather than coarse sand and gravel, reducing extraction possibilities. While volcanic rocks cover a limited area of sub-Saharan Africa, in paleosoils and fractures between lava flows they can produce high groundwater yields and supply springs (MacDonald & Davies, 2000). In other volcanic areas, however, groundwater storage can be highly limited (Walling, 1996).

While geology is an important factor in African groundwater distribution, current and past climatic conditions also play a significant role. In terms of current conditions, the hydrologic function and distribution of groundwater is highly correlated with rainfall patterns. In more arid areas (Sudano–Sahelian regions and Southern Africa) groundwater recharge is important and groundwater systems tend not to be connected to surface systems. In humid regions (Gulf of Guinea and central Africa) aquifers tend to be connected to river systems and groundwater is a major factor in determining base flow (FAO, 2003b).

In terms of past climatic conditions, a relatively unique feature of Africa is the large volume of non-renewable, fossil groundwater resources located in large sedimentary aquifer systems charged in past pluvial periods (Walling, 1996). The majority of these systems lie north of sub-Saharan Africa. However, some lie partially (continental aquifer, Nubian sandstone, Sahel and Chad watersheds) and others fully (Kalahari) within the region. Though many fossil groundwater supplies are deep underground, according to FAO (2003b: 55) they could be an important water source for some arid African countries. However, when fossil reserves are available and economically exploitable, the debate will remain as to how fast, if at all, mining should occur (see for example Abderrahman, 2003; Delli Priscoli *et al.*, 2004).

Together then these factors suggest that, while sub-Saharan Africa has substantial groundwater supplies, the utility of these supplies is diminished by geology and distribution. Geologically, much of the supply is located in hard rock areas or at great depth, raising abstraction costs. In terms of distribution, groundwater supplies tend to be greatest where there is already substantial rain, reducing their potential value. In fact, over half of annually renewable groundwater supplies are located within just four countries: The Democratic Republic of Congo, The Republic of Congo, Cameroon and Nigeria.

3. Groundwater development in sub-Saharan Africa

Despite potential difficulties, groundwater development has in fact had a long and varied tradition throughout sub-Saharan Africa. Morris *et al*. (1984: 71), for example, report that well gardening has been practiced for hundreds of years in Niger, though it seems clear that the history is much deeper. Traditional groundwater abstraction technologies and sources have included *shaduf, dallou* and *dambos*. Shaduf systems, which may have spread from Egypt, connect a bucket-type device to a pole via a rope. The pole is anchored as a lever on a pivoting base and the bucket is lowered into a shallow well, raised and swung over a field or irrigation canal where it is emptied. Shaduf systems are now most commonly associated with *Fadama* farming in Nigeria (Carter *et al*., 1983). Dallou systems use cattle to lift water from wells 4–5 m deep and are typically associated with ancient dry valleys in northern sub-Saharan Africa (Adams & Carter, 1987). *Dambo* (*bani*) systems, practiced widely in southern and east Africa (Roberts, 1988), utilize groundwater from seasonally waterlogged depressions. Oasis agriculture in the Sahelian region, the "singing wells" of east Africa, and simple calabash systems, for example as used by the Dogon in Mali, are other examples of "traditional" groundwater systems for agricultural and livestock use. In many areas, these traditional systems are now being replaced by modern technologies including fossil fuel and electricity driven pumps.

It is difficult to calculate the current area under groundwater irrigation in sub-Saharan Africa, or the geographical distribution of groundwater irrigation within the region or the changes in either of those measures over time from published sources. In part this is because of the inherent difficultly in separating groundwater from surface water use in any meaningful way(for example in wetland cultivation). However, the problem is also related to specific details of the sub-Saharan African context. For the region in general, there is poor documentation of irrigated areas as discussed above. For example, Serrano & Carter (1991) found that though FAO, the International Commission on Irrigation and Drainage (ICID) and United States Agency for International Development (USAID) all indicated that Angola had almost no irrigation in the 1980s, in fact there were some 320,000 hectares and nearly 40% of all households participated in irrigated agriculture. Similarly, Carter *et al.* (1983) estimated that there were 1 million hectares of "traditional" irrigation in Nigeria in 1983, whereas AQUASTAT (the FAO's information system on water and agriculture) statistics even today put the irrigation figure at less than one-quarter of that amount.

For groundwater irrigation in particular, there are additional problems. For example, many authors who discuss irrigation in Africa do not differentiate between ground and surface water sources, perhaps because irrigation in sub-Saharan Africa is so limited that published reports tend to focus only on general irrigation issues or the question of expansion potential and not particulars such as source. A second problem appears to be that groundwater irrigation is often small-scale, traditional and/or private and so sometimes falls outside the scope of published analyses which tend to focus on government sponsored irrigation "schemes".

As an example of the overall problem in determining the area under groundwater irrigation, FAO, which has probably made a better effort to understand water use in Africa than any other organization, attempted to identify the areas of Africa under irrigation and to differentiate irrigation by type (FAO, 1987). In total, they listed only 17 specific locations where groundwater was used and in most of those cases, groundwater use was lumped with surface systems in calculating area. The report also cited four countries in which groundwater was used in "traditional" systems, although again area estimates were unclear. A 1995 update (FAO, 1995) provided estimates of groundwater area as a percentage of “equipped” irrigated area for 16 sub-Saharan African nations. Data for other countries were presumably not available. Together the data for the 16 countries totaled around 317,000 hectares with two countries accounting for 96% of the result, South Africa (72%) and Sudan (24%). The 317,000 hectare estimate can clearly be considered low, not only because of missing country data, but also because it seems to include only numbers from irrigation schemes and thus excludes traditional irrigation—a category likely to contain a relatively high proportion of groundwater supply. The FAO’s current database, AQUASTAT, now nominally includes estimates for 21 countries (for seven of those countries, estimated use is zero) and reports 320,000 hectares of land irrigated with groundwater (FAO, 2003a), again almost certainly an underestimate.

To obtain a somewhat better idea of groundwater irrigated area, additional FAO data can be combined with simplifying assumptions. AQUASTAT (FAO, 2003a), using a broad definition of irrigation which includes cropping of wetlands and flood recession planting, estimates that about 5.9 million hectares or 4% (about three-quarters of which is located in Madagascar, Sudan and South Africa) of sub-Saharan Africa’s arable land is under some type of irrigation. The 14 countries for which FAO provides (non-zero) groundwater estimates account for about 3 million hectares of that total. If groundwater irrigated area, as a percentage of total irrigated area, is the same for those countries with data (10.1%) as for those without, then sub-Saharan Africa has about 600,000 hectares under groundwater irrigation. Making a rough adjustment for undercounting, a figure of 1 million hectares of groundwater irrigated area, about 0.8% of total arable land, is probably not unreasonable as a rough approximation of a lower bound.

4. The groundwater economy of sub-Saharan Africa

The figure presented above would seem to indicate that groundwater plays an almost insignificant role in sub-Saharan African agriculture. This is unfortunate given the resource’s possibilities for the reduction of rural poverty reduction (Moench, 2003; Shah *et al.*, 2003), one of the regions most challenging problems. However, a true understanding of groundwater’s role in the region and an understanding of its potential contribution to poverty reduction in the future, requires an understanding of its functions within the sub-Saharan African context. For the agricultural economy, the focus of this paper, these functions can be divided into three areas: crop production, livestock watering and drought mitigation[5].

4.1. Crop production

By the previous estimates, there are some 1 million hectares of crop land under groundwater irrigation in sub-Saharan Africa. If as FAO states (1986: 16), traditional and small-scale farms, still the dominate farm type, are about 1 hectare, then groundwater use might contribute directly to the agricultural livelihoods of some 1 million families. Assuming an average family size in Africa of six, this suggests that about 1.0% of the overall population and 1.5% of the rural population depends directly on groundwater for at least some portion of their agricultural livelihood.

[5]Groundwater, especially in undeveloped form, also provides environmental services, which are not considered here.

In terms of output, AQUASTAT estimates (based on incomplete figures) show that for sub-Saharan Africa's irrigated areas in general, about half is used to produce rice, one-quarter to produce other grains and the rest for other crops or arboriculture (FAO, 2003a). They note, however, that there is substantial variation, especially with respect to rice versus other cereals, by region. In addition, it has been pointed out that crops grown under small-scale irrigation, which may use a disproportionately high share of groundwater, tend to be of the "traditional" variety, such as sorghum or millet, or horticulture (Morris *et al.*, 1984: 97).1 Anecdotal evidence gathered by the author suggests that groundwater is also frequently used for the production of vegetables destined for urban markets.

The use of groundwater in the production of traditional crops and market gardening would seem to suggest that users are relatively small scale and, perhaps, relatively disadvantaged. However, there is also evidence from South Africa and elsewhere in southern and east Africa which reveals that groundwater also plays a role in the production of commercial crops by relatively well off, large-scale farmers. These two sets of seemingly opposing findings are probably an indication that the driving factors behind agricultural groundwater use across sub-Saharan Africa are not uniform and that caution should be used in generalizations, even within a single country.

As with groundwater use by socio-economic sector, the role of groundwater in respect to gender probably also shows a dichotomous pattern. The use of shallow groundwater for small garden irrigation has been noted in Burkina Faso, Niger, Benin, Togo, Zimbabwe, Botswana and other countries (FAO, 1986: 10). In some cases, garden production is the province of women (e.g. see Lovell *et al.*, 1998 for Zimbabwe) and so groundwater use tends to have a direct "pro-women" bias. In Ghana, vegetable production through groundwater use tends to be carried out by men. However, marketing tends to be controlled by women. In contrast, larger scale commercial irrigation such as that mentioned above tends to be male dominated. Again, generalizations on the gendered roles of groundwater use in sub-Saharan Africa should only be made with caution.

4.2 Livestock

Large areas of savanna, semi-desert and desert areas in sub-Saharan Africa are typified by livestock, rather than agricultural economies. In general, cattle density is highest in the Sahel region and roughly along the line from Ethiopia along the rift valley to South Africa and Lesotho (Thornton *et al.*, 2002). Cattle tend to dominate the livestock economy, but sheep, goats and, especially in deserts or near-desert environments, camels can also play important roles. Cattle in particular have a social value in many African societies beyond a narrowly defined production value. As such, they tend not to be used for food (except for milk) in normal times, though during periods of drought or other emergencies they can be consumed or sold as part of a coping strategy.

Especially in arid areas, it appears that groundwater may play a critical role in the maintenance of the livestock economy which itself is the basis of human survival and makes possible human habitation in some areas. As a general indication of the role of livestock in rural livelihoods and the role of groundwater in sustaining those livelihoods, FAO (1986: 137) states that "groundwater is more widespread than surface water in the Sahel, although it is at present exploited mainly for domestic and livestock purposes, from traditional wells with yields too low for irrigation". In the case of Ghana, it has been estimated that 70% of cattle and 40% of other livestock production, accounting for 4.5% of agricultural GDP, is dependent on groundwater use (Obuobie & Barry, forthcoming). Quantification of the contribution of groundwater to sub-Saharan Africa's total livestock economy based on published sources is currently problematic. As some measure of the potential magnitude, the World Bank has estimated that 10% of sub-Saharan Africa's population is directly dependent on livestock and 58% is dependent to some degree (McIntire *et al.*, 1992). Thornton *et al.* (2002) estimate that there are over 160 million poor, roughly one-third of the total population, who keep livestock. Given that a large share of livestock production is likely to be groundwater dependent, the value of groundwater in sub-Saharan Africa's overall agricultural economy and in the livelihoods of its poorest residents is clearly substantial.

4.3. Drought mitigation

Since groundwater supplies are less correlated with rainfall than surface supplies, one of groundwater's key functions can be its ability to mitigate the effects of erratic rainfall or drought on agricultural production. While this function is of global importance, it may be especially so in sub-Saharan Africa where temporal rainfall variability, as outlined above, is amongst the highest in the world. In fact, African pastoral societies have taken advantage of groundwater to mitigate the impact of temporal variation in rainfall supply for centuries. More recently focus has been placed on the role of groundwater in moderating the crop impacts of drought. For example, there was considerable expansion of irrigation in general, including wells, following the 1968–73 droughts in the Sahel (Morris *et al.*, 1984: 14) and numerous papers now highlight that role (e.g. Amad, 1988; Callow *et al.*, 1997).

In contrast to valuations of groundwater supply in crop and livestock production, where relatively straightforward estimates can be made based on total area, number of animals or value of output (if data is available), valuing the drought mitigation value of groundwater is complicated for two primary reasons. First, knowledge that groundwater is available as an alternative to surface or rainwater reduces risk and makes farming and livestock production possible in areas where it otherwise would not occur. Thus the value of some production based on non-groundwater sources, perhaps especially in marginal lands, can in fact be attributed to groundwater. Second, the role of groundwater in drought mitigation highlights the issue of marginal, as opposed to average, valuation of water resources. As shown in the Figure 2, the marginal value of groundwater, that is the value of applying an additional unit of groundwater to agricultural or livestock production, can range conceptually from highly positive to highly negative depending on the availability of other alternative water supplies. The literature on the empirical valuation of agricultural water (water productivity) has yet adequately to address this issue (see, for example, Barker *et al.*, 2003). This is unfortunate as such quantifications would help to ensure a greater appreciation of groundwater resources.

5. Why isn't there more groundwater use in Sub-Saharan Africa?

A question often asked is, why is there not more irrigation, including groundwater irrigation, in sub-Saharan Africa? A common assumption is that the reason is related at least in part to water availability. As the numbers above clearly indicate, aggregate and per capita water availability in sub-Saharan Africa compares favorably with other irrigation intensive regions of the world, though clearly water distribution in the continent is not equal across space or time. So what other reasons may there be? Here four possible explanations are examined.

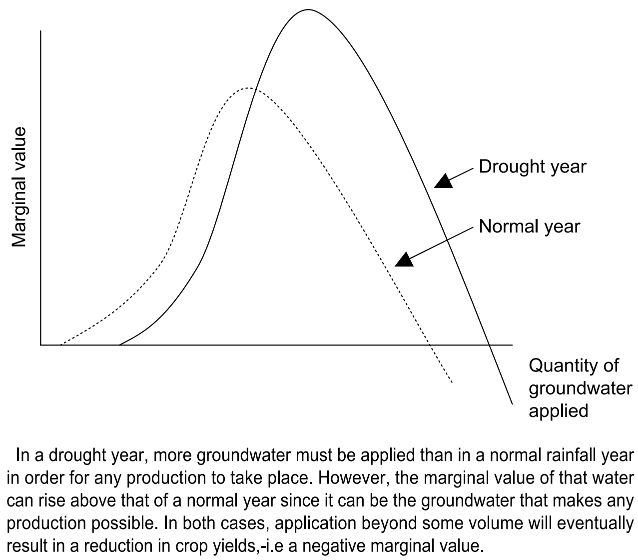

Fig. 2. Conceptual variation in the marginal value of groundwater.

5.1. Geography and farming systems

One primary factor behind the low levels of irrigation development in sub-Saharan Africa is likely to be the relationship between the human and physical geography of the continent. First, much of the ground, as well as surface, water is located in areas where rainfall is sufficient and so irrigation development may not be seen as necessary in some areas or possible in others, at least on a wide scale. Second, in general, Africa is land abundant and people scarce when compared to much of the developing world, in particular Asia. As a result, outside urban areas, farms tend to be relatively small in size not because of high population densities as is the case in Asia, but because there is insufficient labor, given existing technologies, to farm larger areas (Stock, 1995). Under relatively labor-scarce conditions, rainfed agriculture tends to be more remunerative than does irrigated agriculture (Underhill, 1990: 7 and 18). In fact, as suggested by the induced innovation school (Boserup, 1981; FAO, 1986; Serrano & Carter, 1991; Wade, 1995), irrigation tends to rise in response to intensification, which itself is a function of population growth and market development. While such conditions have existed in many parts of Asia for centuries and have intensified since the 1950s and 1960s, they exist only in limited regions of sub-Saharan Africa[6].

5.2. Development costs, infrastructure and capital availability

There is a general feeling that the costs of irrigation development, both ground and surface, in Africa is high (e.g. Kandiah, 1997; Sounou, 1997). From a purely technical standpoint, there are a number of reasons why this may be the case. In areas where groundwater development could be most productive, it

[6]However, the induced innovation argument may apply more to surface water irrigation than groundwater.

tends to be accessible only within fractures. As such, it can be more difficult to locate, resulting in low percentages of successful borehole sitings and increasing average costs. In addition, when groundwater is found, either in fractures or in shallow aquifers, yields tend to be relatively low, increasing the fixed investment cost per unit of water extracted. Even in alluvial regions where extraction of shallow groundwater might be assumed easiest, low gradients and the nature of parent material promote coverage with fine and very fine sediments rather than sand and gravels more conducive to groundwater supply and abstraction. Fossil groundwater supplies, where present, tend to be deep, greatly increasing pumping costs. Furthermore, soil quality in some areas of Africa may be such that the potential crop yield resulting from irrigation may be relatively low. It has also been suggested that many technically attractive sites for irrigation are far from markets, reducing the value of output and return from investment, at least for commercial crops (Morris *et al.*, 1984: 13).

In addition to physical factors, there also appear to be socio-economic and political factors which cause groundwater development costs to be higher, or returns to irrigation investment to be lower, in Africa than, for example, in south Asia or China. Reasons typically cited include lack of local manufacturing capability, high duties on imported equipment, high energy costs and poor supporting infrastructure such as road networks and electrification. Capital availability and the possibility of mobilizing capital may also be lower in Africa and the alternatives to which capital may be put may make irrigation investment less favorable in Africa than elsewhere. For example, commercial and concessional food import programs may lower domestic production prices, reducing the return on any irrigation investment and encouraging the use of capital elsewhere.

5.3. National policy

In some cases, there is explicit evidence that national and donor policy has undermined groundwater development. For example, Makombe *et al.* (2001), summarizing the work of others (Bell *et al.*, 1987; Andreini, 1993), describe a ban by the former white government on the traditional use of *bani* (*dambo*) irrigation in Zimbabwe. In Nigeria, modern irrigation systems have been developed which required the flooding of bottom lands which otherwise could have been farmed under *fadama* systems. Owing to the low relief, the land lost to possible low-cost groundwater irrigation was sometimes as much as that irrigated under the new systems (Barbier & Thompson, 1998). In fact, the general push by governments and donors, at least up until the last decade, to develop large surface schemes, which generally have not lived up to expectations, may have drawn resources away from groundwater development and turned farmer sentiment away from irrigation expansion.

The reasons for the poor performance of the large-scale schemes are many, but some of the possible social factors are especially relevant to future groundwater development. For example, the development of modern irrigation has tended to require the usurpation of customary land rights, making the projects less attractive to current farmers. In addition, the development of modern schemes has often required cooperative water management, a concept foreign to many, but not all (Grove, 1993; Adams *et al.*, 1994; Adams *et al.*, 1997) traditional African farming systems, so making implementation more difficult. Large-scale projects have also tended to negate the risk management strategies built into traditional farming systems and have made farmers dependent on the advice and, sometimes poor, service of governments, increasing perceived risk (Carter & Howesam, 1994). In contrast, there is some indication that private groundwater development would have been more consistent with indigenous water rights (Howsam, 1999) and thus more likely to have succeeded.

5.4. Misperception

Finally, it may be that the very premise behind the question "why isn't more groundwater used in sub-Saharan Africa?" is at least somewhat misplaced. In part, this may be because of the general inaccuracy of irrigation statistics in Africa as discussed above. This may itself be a function of the timing of the last "small-scale irrigation for Africa" push of the 1980s and hence the last period of major focus on data. A perusal of the bibliography for this paper will reveal a high proportion of studies resulting from work of that period. What more recent data that is available suggests that change has taken place. For example, the number of tube-wells in three states in Nigeria is reported to have been 15,000 in 1990, up from 80 in 1983 (Sounou, 1994)[7] and a recent report sponsored by the International Water Management Institute on the Limpopo basin in South Africa revealed some 35,000 boreholes and Asian-style rates of growth in new well construction (Tewari, forthcoming). A second report showed similar growth rates and numbers for Botswana (Water Surveys Botswana, 2002) and a review of groundwater use in Kenya indicated that overexploitation is already a problem in some areas (Bakker, 1997). This suggests that there may in fact be more groundwater used than is commonly believed and, perhaps more importantly, that rapid growth in groundwater use may be occurring in at least some parts of sub-Saharan Africa. Thus the time for developing and implementing well thought out governance structures, which fit the various realities of the African context may already be upon us.

6. Conclusion and directions for future research

This paper has attempted a review of groundwater use in sub-Saharan Africa based on published material so as (1) to provide an understanding of the state of groundwater development and the size of the groundwater economy and (2) to identify knowledge gaps and promising directions for future research to support both the possible development of additional resources and the governance of those resources. A primary conclusion of the paper, and thus a call for additional research in and of itself, is that a systematic picture of sub-Saharan Africa's groundwater economy has yet to be developed.

That said, it is clear that sub-Saharan Africa's groundwater resources are substantial and greater in per capita terms than in some of the worlds' largest groundwater economies such as India and China. However, the spatial distribution of Africa's groundwater supplies and other physical factors in many ways detracts from its suitability for human use. In part for that reason, the absolute size of Africa's groundwater economy is small, both in absolute terms and relative to Asia. Calculations from existing data suggest that perhaps 1.5% of rural households are served by groundwater for agricultural purposes. In contrast, the figures for China and India may be in the order of 30 and 50% respectively.

Analysis also suggests that the value of groundwater in the sub-Saharan African economy may in fact be higher than these numbers indicate. In some areas, groundwater provides the foundation for human

[7]Although potential development was put at nearly one quarter of a million wells.

habitation as well as agricultural and livestock production and so forms the basis of some local and regional agricultural economies and the livelihoods they support. In addition, groundwater serves key drought mitigation functions and thus has, at times, an extremely high marginal value not captured in average figures. As a result, the appropriate methodology for assessing the value of current groundwater use in sub-Saharan Africa may be rather different from that for surface irrigation in Africa or groundwater irrigation in some other developing countries where values can be meaningfully calculated based on water markets or average contribution to agricultural output. Further, images of African groundwater use from a decade or two ago may misrepresent the present and provide an inaccurate guide to the future.

In terms of research priorities to support the development and sustainable utilization of groundwater in sub-Saharan Africa, the analysis suggests three areas of focus. First, as mentioned, better basic data on current agricultural groundwater use and its value to African society is needed. This is important both to help researchers and policy makers appreciate the current value of the resource, but also to provide a base from which future development plans can be built (or curtailed). Country specific overviews would provide a meaningful first start in this respect. Second, reasons for the differences in groundwater utilization rates both within and across sub-Saharan African countries need to be explained if meaningful policies and programs for future groundwater development are to be formulated. In many parts of sub-Saharan Africa, groundwater is yet to be developed, in others it has been sustainably used over long periods of time and in still others depletion is already a problem. For underdeveloped areas, there may be lessons from China, India and elsewhere for expansion of use. In those areas which have long histories of well-managed use, for example in the oases of the north, there may be governance lessons which can be applied in other regions of the developing and developed world. In those areas where resources have not been developed, constraints to development need to be better understood and methods for overcoming those constraints, if deemed practical, developed.

Related to the previous points, a better understanding of the potential for future groundwater development needs to be created which links technical feasibility with economic and political realities. We must be careful to remember that the problems of many large-scale surface irrigation systems in the past will not necessarily be solved by a simple switch in emphasis to small-scale groundwater systems. The point of new research should not be simply to find technical means to increase groundwater availability for agriculture. Rather it should be to understand the conditions under which use can be viably expanded. The fact that there is not now more groundwater use may be best explained by the rationality of African farmers in their prevailing physical and politico-economic settings. African farmers know their environment, know their systems and know how to adopt useful technologies. When conditions are amenable, farmers respond. For example, despite the supposed high costs of irrigation development in Africa, farmers in southeastern Ghana have gone from hand dug wells, to diesel pumps, to electrification over a relatively short period. Similarly, diesel pump technology and techniques introduced in Nigeria after the oil boom spread quickly elsewhere in the region. Farmer's with such skills and ability know best themselves if additional area can be irrigated with ground, or surface, water. In many cases, the fact that they are not choosing to do so probably says that, without some change in the overarching political or economic system, increased irrigation is uneconomic. The point of future research and future development policy, as related to groundwater in sub-Saharan Africa, should be to understand both where additional development is possible and, equally important, where and why it is not.

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