Agricultural groundwater use and rural livelihoods in sub-Saharan Africa: A first-cut assessment

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Abstract The rapid expansion in agricultural groundwater use in the last few decades has transformed rural economies in large parts of the developing world, in particular South Asia and North China. There has been no such "Groundwater Revolution" in most of sub-Saharan Africa and little is known about the actual role of groundwater use in supporting agricultural livelihoods in the region or opportunities to expand this role in the future. Published literature has been reviewed to paint a preliminary, region-wide picture of the contribution groundwater makes to agriculture, and in turn to rural livelihoods, within sub-Saharan Africa. The findings indicate that groundwater is used on only 1–2 million hectares of cropped area, directly contributing to the livelihoods of 1.5–3% of the rural population. Groundwater also plays a critical role in the vital livestock sector as well as an important indirect role in the supply of domestic water to agricultural households. While data are lacking, these latter two roles likely surpass the direct importance of groundwater to crop production. This suggests that an understanding of the value of agricultural groundwater use in support of rural livelihoods in sub-Saharan Africa should be based on different models than have typically been applied in Asia.

Résumé L'expansion rapide de l'utilisation des eaux souterraines pour l'agriculture, durant les dernières décennies, a transformé les économies rurales de plusieurs parties du monde, et en particulier en Asie du Sud et dans le Nord de la Chine. On connaît peu le rôle qu'aurait cette ≪Révolution de l'Eau Souterraine≫ sur les moyens de subsidence agricole dans la plus grande partie de l'Afrique Sub-Saharienne, et dans les régions où se présenteraient cette opportunité. Les publications sur ce thème ont été revues de manière à décrire une image préliminaire et régionale, de la contribution des eaux souterraines à l'agriculture, du point de vue du milieu rural en Afrique Sub-Saharienne. L'eau souterraine est utilisée pour 1 à 2 millions d'hectares cultivés, contribuant directement à 1.5 à 3% de la population rurale. L'eau souterraine joue également un rôle critique pour l'élevage, ainsi que pour l'alimentation en eau domestique des fermiers. Bien que les données sont manquantes, ces deux derniers rôles devraient surpasser l'importance directe des cultures. Ceci suggère qu'une compréhension de la valeur de l'eau souterraine agricole dans le milieu rural de l'Afrique Sub-Saharienne, devrait être basée sur des modèles tels que ceux qui ont été typiquement appliqués en Asie.

Resumen La rápida expansión en el uso de agua subterránea para agricultura en las últimas décadas ha transformado las economías rurales en grandes partes del mundo en desarrollo, en particular el Sur de Asia y el Norte de China. No ha existido algo como "Revolución de Agua Subterránea" en la mayor parte de África sub-Sahariana y se conoce poco acerca del papel actual del uso del agua subterránea en el apoyo de subsistencias rurales en la región o de oportunidades para expandir este papel en el futuro. Se ha revisado la literatura publicada para obtener un marco preliminar regional de la contribución que el agua subterránea hace a la agricultura, y a su vez a las subsistencias rurales, dentro de África sub-Sahariana. Los resultados indican que el agua subterránea es usada en solo 1–2 millones de hectáreas de área cultivada, contribuyendo directamente a las subsistencias del 1.5–3% de la población rural. El agua subterránea también juega un rol crítico en el sector fundamental de ganadería así como un rol indirecto importante en el abastecimiento de agua doméstica en granjas agrícolas. Aunque faltan datos, estos últimos dos roles probablemente sobrepasan la importancia directa del agua subterránea en la producción de cultivos. Esto sugiere que un entendimiento del valor del uso del agua subterránea en agricultura en apoyo de las subsistencias rurales en África sub-Sahariana debería de basarse en modelos distintos de los que han sido aplicados típicamente en Asia.

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Introduction

So geographers, in Afric-maps,
With savage-pictures fill their gaps;
And o'er unhabitable downs
Place elephants for want of towns.
Jonathan Swift (1667–1745)

Groundwater development has played a fundamental role in fueling agricultural growth in many parts of the developing world, especially Asia. For example, groundwater accounts for more than half of all irrigation supply in South Asia and perhaps 30% in the grain belts of north China. The rapid growth in use in these and other regions over the past few decades has played a vital role in maintaining the rise in grain output associated with The Green Revolution. While groundwater use is not without its problems and sustainability issues are never far from conversations, there can be no question that its utilization has helped to lift millions out of poverty and worked to push global foodgrain prices ever lower.

Available evidence suggests that, like Asia, sub-Saharan Africa[1] has both substantial groundwater resources and a long tradition of agricultural groundwater use. Unlike Asia, however, sub-Saharan Africa has missed both the Green and Groundwater revolutions, and it is the only major region in which per capita food production has actually declined over the last 30 years. In contrast to Asia, if there is an agricultural groundwater "problem" in sub-Saharan Africa, it seems generally to be one of underdevelopment rather than over abstraction.

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 agricultural groundwater economy of sub-Saharan 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 as the cartographers described by Swift above were in filling maps centuries ago. How much groundwater is used in agriculture? What is the contribution of agricultural groundwater use to rural livelihoods? How can we measure such a contribution in the sub-Saharan African context? Under what conditions should agricultural groundwater development in sub-Saharan Africa be pursued and what research is needed to guide those decisions? These questions remain largely unanswered.

Because of the poor state of knowledge on agricultural groundwater use and its impact on rural livelihoods within the sub-Saharan Africa setting, the goal of this article is to develop as full a picture as possible based on published sources and a series of national case studies so as to consolidate known information, highlight critical gaps, and inform further research on agricultural groundwater use and its potential role in solving Africa's agricultural water and poverty problems. To do this, the report is divided into three parts. In the first, a brief overview of the region's groundwater resources and their relation to agricultural demand 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 groundwater economy and its role in supporting rural livelihoods. Secondly, given that available evidence does in fact suggest a relatively small size for the agricultural groundwater economy, the report examines a number of possible explanations so as to shed light on sub-Saharan Africa's unique features. Finally, the report provides a set of considerations for future analysis of sub-Saharan Africa's agricultural groundwater economy and how research might serve to improve both development and conservation of the critical resource.

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. The Food and Agriculture Organisation of the United Nations States (FAO) states that "The information available is uneven and very poor for some of the African countries" (FAO 2003a, 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 2003b). Since sub-Saharan Africa has about 11% of the world population (FAO 2003b) it can not, 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 is not equal and the continent probably 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] There are published reports with varying degrees of detail on the groundwater resources and hydrology of some regions and specific areas (e.g. Burke 1994, 1996; Jones 1985).

[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] Much more hydrogeologic information on specific locations is available in grey literature and project reports. However, there is presently no systematic collection of this information.

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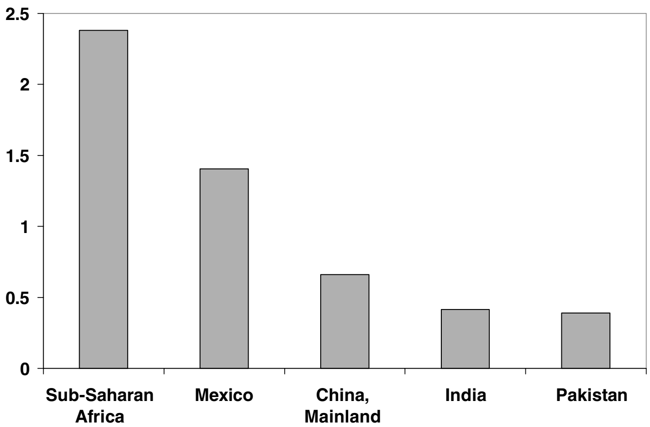

Fig. 1 Annual renewable groundwater supplies, sub-Saharan Africa and selected countries, 1,000 m^3 per person. Source: (FAO 2003b)

Africa's hydrogeology has also recently been summarized at regional levels in Zektser and Everett (2004). However, as put by Walling: "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). Using national estimates by FAO, internally renewable groundwater supplies in sub-Saharan Africa can be placed at around 1,500 km^3/yr (FAO 2003b).[3] This compares with 800 km^3/yr in China and 400 km^3/yr 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 3 times the per capita groundwater availability of China and nearly 6 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 and Davies (MacDonald and Davies 2000), groundwater availability is primarily a function of geology. As such, they and others (Foster 1984; Walling 1996) divide the region into 4 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 and Davies 2000). Crystalline basement rock contains groundwater in the weathered mantle as well as fracture zones. According to Wright and Burgess (1992), the role of such rock as a general supply source is fairly limited due 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 and Davies (2000) point out, unconsolidated sedimentary rock is often found in river beds, and so its groundwater may be especially important for human use due to potential ease of access. However, it has also been noted (Purkey and Vermillion 1995) that many African river systems are 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 paleosols and fractures between lava flows they can produce high groundwater yields and supply springs (MacDonald and 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 2003a).

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 in North Africa. However, some lie partially (Continental aquifer, Nubian Sandstone, Sahel and Chad watersheds) and others fully (Kalahari) within the sub-Saharan region. Though many fossil groundwater supplies are deep underground, they can be an important water source for some arid African countries (FAO 2003a). However, when fossil reserves are available and economically exploitable, the debate will remain as to how fast, if at all, mining should occur.

Together then, these factors suggest that, while sub-Saharan Africa as a whole 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. Distributionally, groundwater supplies tend to be greatest where there is already substantial precipitation, reducing value for human use. In fact, over half the annually renewable groundwater supplies are located within just four countries: The Democratic Republic of Congo, The Republic of Congo, Cameroon and Nigeria. Thus analyses of groundwater's potential for agricultural use need to focus on regional, or even local, rather than continental scales.

[3] Separating groundwater from surface water estimates is complicated because of the interchange between the two systems. FAO separately calculates surface water, groundwater, and their overlap. The numbers presented here are for groundwater only. However, the estimated surface water/groundwater overlap is almost as large as the groundwater estimate. It should also be noted that the estimate for sub-Saharan Africa was derived by adding data from individual countries.

[4] Or three zones depending on whether consolidated and unconsolidated sediments are considered separately.

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Agricultural groundwater development in sub-Saharan Africa

Despite potential difficulties, agricultural groundwater development has in fact had a long and varied tradition throughout sub-Saharan Africa. Morris et al. (1984), for example, report that 'well gardening' (garden irrigation from a well) has been practiced for hundreds of years in Niger, though it seems clear that the history is much deeper. Traditional groundwater abstraction technologies 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* (inland valley) 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 and Carter 1987). *Dambo* (*bani*) systems, practiced widely in Southern and East Africa (Roberts 1988), utilize groundwater from seasonal wetlands. Oasis agriculture in the Sahelian region, the "singing wells" of east Africa, and simple calabash- or gourd-scooping systems (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, the geographic 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 meaningfully separating groundwater from surface water use (for example in wetland cultivation). However, the problem is also related to specifics of data collection and accumulation in the region. For sub-Saharan irrigation in general, there is poor documentation of irrigated area as discussed above. For example, Serrano and Carter (Serano and Carter 1991) found that though FAO, the International Commission on Irrigation and Drainage (ICID) and the US Agency for Internatioanl 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.

For groundwater irrigation in particular, there are additional problems. For example, many authors discussing irrigation in sub-Saharan Africa do not differentiate between ground and surface water sources, perhaps because irrigation in the region 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. In addition, 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. Finally, groundwater is often used for agriculture only in cases of low rainfall or drought. Thus there may be significant differences in groundwater irrigated area between years, at least at local and perhaps regional levels.

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 area 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, though again area estimates were unclear. There was a reassessment undertaken in 1995 (FAO 1995), which provided estimates of groundwater area as a percentage of "equipped" irrigated area for 16 sub-Saharan Africa nations. Figures for other countries were presumably not available. Together the figures for the 16 countries totaled around 317,000 hectares with two countries accounting for 96% of the figure, 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 agricultural groundwater supply. FAO's current data base, Aquastat, now nominally includes estimates for 21 countries, though for seven of those countries estimated use is zero, and reports 320,000 hectares of land irrigated with groundwater (FAO 2003b), again almost certainly an underestimate.

A set of country case studies which attempted to gather information not available in the international literature provides an initial indication of the possible extent of undercounting and further highlights problems of definition (Obuobie and Giordano, in press). The results of the studies, carried out in 9 countries, showed a range of variation in agricultural groundwater use estimates vis-à-vis Aquastat figures. On one extreme is Zimbabwe (Masinyandima, in press), a country for which Aquastat provides no information on groundwater. The Zimbabwe report's author estimated 80,000 hectares of agricultural land under groundwater irrigation, a figure which would increases the entire "known" area for sub-Saharan Africa by 25%. However, one quarter of this 80,000 hectares was related to dambo cultivation, a use recorded by Aquastat but counted as surface water irrigation in its "Other Cultivated Wetlands" category. Other Cultivated Wetlands amount to more than 1 million hectares for sub-Saharan Africa as a whole and if counted as groundwater would triple current estimates.

At the other extreme is South Africa (Tewari, in press), sub-Saharan Africa's largest groundwater user according to Aquastat. The author of that report, which examined only the Limpopo basin, found no available information on groundwater irrigation beyond that recorded by Aquastat.

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Table 1 Comparison of groundwater use estimates, Aquastat and country studies (in hectares)

	Aquastat	New Estimate	Difference
Burkina Faso	N/A	N/A	N/A
Ghana	0	16,000	16,000
Kenya	666	775	109
Mali	2044	4983	2,939
Niger	N/A	N/A	N/A
South Africa	228,600	228,600	0
Somalia	N/A	0	0
Zambia	2,505	6750	4,245
Zimbabwe	N/A	80,000	80,000
Total	233,815	337,108	103,293
% Increase			44%

Source: (FAO 2003b) and (Obuobie and Giordano, in press)

As shown in Table 1, the other countries in the study fell between Zimbabwe and South Africa in terms of difference with Aquastat statistics. For the 9 countries involved, the estimates provided by the country studies increase the recorded area under groundwater irrigation by approximately 40%. Still it should be remembered that the case studies also relied primarily on secondary data, which themselves probably underestimated the area.

Extrapolating for missing Aquastat data (adjusting for the information provided above, and making some simplifying assumptions) provides some additional insights into the possible extent of agricultural groundwater use in sub-Saharan Africa. Aquastat (FAO 2003b), 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 Aquastat 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. Adjusting by the underestimate (∼40%), documented in the country studies discussed above, increases the figure to around 850,000 hectares. Knowing that even those numbers are likely underestimates, a figure of 1 million hectares of area at least partially irrigated with groundwater, about 0.8% of total arable land, is probably not unreasonable as a rough approximation. As noted though, this figure does not include dambo irrigation which could again double the number.

Groundwater and rural livlihoods in sub-Saharan Africa

While the figures above indicate that there is likely more agricultural groundwater use in sub-Saharan Africa than generally thought, even these new, higher figures would seem to indicate that groundwater plays an almost insignificant role in sub-Saharan African agriculture, especially compared to South Asia and parts of China. However, a true understanding of groundwater's role in sub-Saharan African agriculture requires an understanding of its functions specifically within the sub-Saharan African context. These functions can be divided into three main areas: crop production, livestock watering, and rural domestic supply. The additional role that groundwater plays in providing environmental services and their connection to agriculture, while acknowledged, is not explicitly considered here.

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 (FAO 1986), traditional and small scale farms, still the dominant farm type, are about 1 hectare, then groundwater use might contribute directly to the rural livelihoods of some 1 million families. Assuming an average family size in Africa of 6 individuals, this suggests that about 1% of the overall population and 1.5% of the rural population depends directly on groundwater for at least some portion of their agricultural livelihood.

The country studies introduced above (Obuobie and Giordano, in press) indicate that a range of crops are produced using groundwater. Table 2 shows the apparent variation by farm type. Small scale producers tend to use groundwater for production of vegetables either for home consumption or sale and sometimes for "traditional" cereals such as millet (e.g. in Mali). Commercial users appear more likely to grow cereals. While obviously not comprehensive, the studies also indicate a trend in agricultural groundwater use by region. In West Africa use appears to be associated primarily with small scale producers while in Southern Africa there is considerable commercial consumption. East Africa may fall somewhere in between.

Livestock

While in much of the world crop production is the mainstay of agricultural economies, agriculture in large areas of savanna, semi-desert and desert areas in sub-Saharan Africa are dominated by livestock production. 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

Table 2 Documented use of groundwater for crop production

Burkana Faso	Vegetables
Ghana	Vegetables
Kenya	Grain, Vegetables
Mali	Millet
Niger	N/A
South Africa	Not indicated but probably grain
Somalia	None or little
Zambia	Sugarcane, Wheat, Coffee, Vegetables
Zimbabwe	Vegetables, cassava, grains

(Obuobie and Giordano in press)

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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 plays 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 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" (FAO 1986, 137). As an example, Githumbi (Githumbi, in press) found that in Somalia all productive groundwater use was for livestock production, with none used for crops. Further, in virtually all of the counties examined in Obuobie and Giordano (in press), livestock production was found to be primarily dependent on groundwater for all or part of the year. Still, quantification of the contribution of groundwater to sub-Saharan Africa's total livestock economy based on published sources is 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 and other writers (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, probably majority, share of livestock production is 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 and quite possibly greater than its role in crop production.

Rural water supply

While only indirectly related to agriculture, groundwater plays a major role in providing domestic supplies to rural African framers. Though precise numbers are difficult to come by, it is likely that in fact most domestic water supply in rural sub-Saharan Africa is currently supplied by groundwater and that expansion in rural supplies in the near future will likely be from groundwater sources. Further, within the rural groundwater sector, domestic use, rather than agriculture or livestock, appears to account for the vast majority of demand. This was true for example in all cases examined in (Obuobie and Giordano, in press) with the exception of South Africa. Groundwater thus provides the foundation for rural livelihoods whether or not it is directly used in agricultural production. In fact, as with livestock, it is quite likely that this role is greater in support of rural livelihoods than is actual crop production.

Why is there not more groundwater use in sub-Saharan Africa?

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

Geography and farming systems

One primary factor behind the low levels of groundwater irrigation development in sub-Saharan Africa is the relationship between the human and physical geography of the continent. First, much of the groundwater, 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 regions 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 of urban areas, farms tend to be relatively small in size due not to 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, rain fed agriculture tends to be more remunerative than irrigated (Underhill 1990). In fact, as suggested by the induced innovation school—whose work admittedly developed more out of surface than groundwater systems (Boserup 1981; FAO 1986; Serano and 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. Further, because surface irrigation and its associated groundwater recharge have not occurred on a widespread basis in sub-Saharan Africa for the reasons just described, conjunctive surface and groundwater systems have not developed as has been the case in some of the world's largest groundwater using regions including parts of South Asia and northern China.

Development costs, infrastructure and capital availability

There is a general feeling that the costs of irrigation development, both from groundwater and surface water, 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 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,

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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).

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 lower, in sub-Saharan Africa than, for example, 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 to mobilize capital may also be lower in Africa, and the alternatives to which capital may be put may also make irrigation investment less favorable in sub-Saharan 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.

National policy

In some cases, there is explicit evidence that national and donor policy has undermined groundwater development. For example, Makombe and other writers (Makombe et al. 2001), summarizing the work of others (Bell et al. 1987; Andreini 1993), describe a ban by the former 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. Due 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 and Thompson 1998). In fact, the general push by governments and donors, at least up to the last decade, to develop large surface schemes, which many times 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, and 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 and 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.

Misperception

Finally, it may be that the very premise behind the question "why is there not more groundwater use in sub-Saharan Africa?" is misplaced, at least to some degree. In part this is because of the general inaccuracy of irrigation statistics in sub-Saharan Africa as discussed above. This may itself be partly a function of the timing of the last push towards "small-scale irrigation for Africa" during the 1980s and hence the last period of major focus on data. A perusal of the references list for this report will reveal a high proportion of studies resulting from work of that period. More recent data are available, which suggest 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 though still far short of the estimated quarter-million well potential (Sounou 1994). Further, a survey of the Limpopo basin in South Africa revealed some 35,000 boreholes and Asian-style rates of growth in new wells construction (Tewari, in press), 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.

A second reason is related to the difference between the role of agricultural groundwater in support of rural livelihoods in sub-Saharan Africa, Asia and other regions. Most work on the role of agricultural groundwater use in Asia, especially at national or continental scales, rightly focuses on crop production, i.e. the area or quantity of grains produced using groundwater or the value of groundwater markets. In sub-Saharan Africa, however, the role of groundwater in the production of livestock and providing domestic supplies for farmers and farm families may be much larger than its role in crop production. While a quantification of these factors would not bring estimates of sub-Saharan Africa use even close to that of Asia, it does indicate that direct comparisons of the contribution across continents should be done

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with care and that the methodologies employed should be context specific.

Conclusion and outstanding questions

This report attempted a review of agricultural groundwater use in sub-Saharan Africa so as to:

1. Provide an understanding of the state of agricultural groundwater development and its role in supporting rural livelihoods and
2. 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, and thus a call for additional research in and of itself, is that a systematic picture of sub-Saharan Africa's agricultural 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 detract from its suitability for agricultural use. In part for that reason, the absolute size of Africa's agricultural groundwater economy is small, both in absolute terms and relative to Asia. Calculations from existing data suggest that perhaps 1.5% of rural households use groundwater for crop production. 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 suggest. Groundwater plays a substantial role in supporting the livestock economies in much of sub-Saharan Africa. Further, groundwater provides the foundation for human habitation as well as agricultural and livestock production through domestic supplies and so forms the basis of some local and regional agricultural economies and the livelihoods they support. In fact, it is likely that the contribution of groundwater to rural livelihoods via its role in livestock production and domestic supplies is greater than its direct role through crop production. As a result, the appropriate methodology for assessing the value of current groundwater use in sub-Saharan Africa may be rather different than that for surface irrigation in Africa or groundwater irrigation in other developing countries where values can be meaningfully calculated based on contribution to crop output or the size of water markets. Further, images of agricultural 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 agricultural groundwater in sub-Saharan Africa, the analysis suggests three areas of focus. First, as mentioned, better basic data on current agricultural groundwater use, usage trends and the value of groundwater to sub-Saharan African agriculture are 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. Compilations of grey literature and project reports would also be useful. 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 some 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 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 agricultural groundwater use may be best explained by the rationality of African farmers in their prevailing physical and politico-economic settings. African farmers know their environments, 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 transitioned from hand dug wells, to diesel pumps to electrification over a relatively short period. Similarly, and related, diesel pump technology and techniques introduced in Nigeria after the oil boom spread quickly elsewhere in the region. Farmers with such skill 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 and unsustainable. 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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