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139

Shallow Groundwater in the Atankwidi Catchment of the White Volta Basin: Current Status and Future Sustainability

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Front Cover: Left: A typical hand-dug shallow well in the Atankwidi Catchment (photo credit: Murali Krishna Gumma); and Right: Tools used and processes involved in making a hand-dug shallow well in the Atankwidi Catchment (photo credit: Joost van den Berg).

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Project

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Contents

Summary

Over the past years, recurrent spells of drought and flooding have led to food insecurity and increasing poverty in most of northern Ghana where formal irrigation is beneficial only to a limited number of farmers. In the White Volta Basin, and particularly in the Upper East Region (UER), hundreds of rainfed smallholder farmers began developing their own irrigation systems in the late 1980s abstracting shallow groundwater in the lowlands and from the dry riverbeds of two tributaries of the White Volta River Basin - Atankwidi and Anyere.

This report presents findings of a detailed study conducted in the 286 square kilometer (km^2) Atankwidi Catchment. This study was aimed at (1) delineating areas under shallow groundwater irrigation (SGI) using high resolution images, and (2) determining the volume of water available in storage in the underlying shallow aquifer.

Standard methodologies were used to delineate land use/land cover (LULC) classes within the catchment (including areas under SGI) using QuickBird images from May 2008. The images were classified using an unsupervised classification algorithm (ISODATA), after which classes were merged using bi-spectral plots, intensive ground truthing and Google Earth imagery. Geophysical surveys involving electromagnetic transects and vertical electrical sounding were conducted to determine the geometry of the underlying aquifer, from which estimates could be made of the volume of water held in storage.

Results of LULC mapping reveal that SGI is practiced exclusively on lowland areas and on fluvisols along the riverbed on 387 hectares (ha) (1.4%). Rainfed areas constitute 15,638 ha (54.7%) of the catchment, with the remaining (43.9%) being other LULC types. Comparison of these results with a previous study in which QuickBird data from 2005 was analyzed indicates an increase in areas under SGI between 2005 and 2008.

Results of the geophysical surveys revealed that the thickness of the underlying aquifer varies from 2.6 to 13.7 meters (m). The aquifer has low resistivity in the range of 3.2-55.3 ohm-m suggesting high clay content. The total volume of water that can be stored annually in the underlying aquifer was estimated to be approximately 3.7×10^8 m^3, which is by far more than what is actually applied for irrigation annually (8.9 x 104 m^3 - 2 liters/day/square meter (m^2) at planting stage and 5 liters/day/m^2 at flowering stage). The quality of the water was found to be suitable for both drinking and irrigation, based on the physico-chemical parameters tested (bacteriological parameters were not tested).

Shallow Groundwater in the Atankwidi Catchment of the White Volta Basin: *Current Status and Future Sustainability*

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Introduction

Ghana, like many other countries in sub-Saharan Africa (SSA), relies heavily on agriculture for economic prosperity. Agriculture employs approximately 60% of the nation's economically active population, and contributed approximately 38% of the country's foreign exchange earnings in 2008 (ISSER 2009). Regrettably, agriculture in the country has, for many years, remained at subsistence level, with many farmers using rudimentary technology to produce approximately 80% of Ghana's total agricultural output. About 90% of farm holdings are less than 2 ha in size, resulting in low food production (GNIB 2008). This can partly be blamed on the untapped irrigation potential of the country, and an undue reliance on erratic rainfall. Though irrigation has been identified as holding the key to sustained food availability in the face of climate change and population increase, investments in irrigation development (including research) in the country have been inadequate. The irrigation potential of Ghana has been estimated to be 1.9 million hectares (Mha), of which only about 2% have been realized (FAO 1997).

Irrigation in Ghana can be traced to a little over a century ago (Smith 1969). As early as 1880, irrigation was practiced on a small-scale basis in the Keta area on land above flood level between the lagoon and the sandbar separating it from the sea (Kyei-Baffour and Ofori 2006). Agodzo and Bobobee (1994) present evidence of some form of shallow tube well irrigation in the southeastern part of Ghana in the 1930s. During this period, colonial agricultural services in the northern part of the country also promoted the practice of small-scale irrigation, specifically around Pungu and Telania. Local farmers were shown how to dig and line small wells, which could be used for the production of a wide variety of vegetables during the dry season. The farmers picked up this practice and passed it on to their children. Although the government, since independence, has made efforts in developing the formal irrigation sector, the practice of small-scale informal irrigation (e.g., SGI) is still prominent across the country, especially in the northern parts. Drechsel et al. (2006) noted that the area cropped under the informal irrigation sector in Ghana is greater than that of the formal sector.

SGI is one of many small-scale irrigation techniques adopted by farmers in northern Ghana to improve food security. Farmers practice SGI during the dry season, mainly in inland valleys where water is retained in the alluvial material close to the river (van den Berg 2008). Farmers use simple tools like an axe, hoe, bucket and bowls to dig the wells. A rope is tied to a bucket and the soil is collected and pulled out of the well until the water table is reached. A collaborative study between IWMI and the International Food Policy Research Institute (IFPRI) revealed that, wells for SGI have diameters ranging between

70 and 100 centimeters (cm) while they have a depth ranging between 1 and 9 m (Namara et al. 2010).

Since agricultural extension services are missing for most informal irrigators (Drechsel et al. 2006), most farmers using SGI depend on the knowledge and experience of their colleagues to adopt irrigation techniques. The gradual expansion of SGI techniques started from Pungu and Telania, and spread slowly from there to Mirigu and Doba in the lower parts of the Anayere catchment, and were later transferred to Kandiga in the Atankwidi Catchment, from where it was further spread to other parts of northern Ghana (Laube et al. 2008). At the same time, farmers from medium-scale irrigation schemes, who lacked access to land and water, or simply wanted to escape the control of the agricultural bureaucracy in the government controlled irrigation schemes, started to develop shallow groundwater pump irrigation in the lower parts of the catchments. Over the last 15 years, the practice of SGI has gained widespread prominence in northern Ghana, with the construction of more and more wells and dugouts for dry season irrigation (van den Berg 2008).

The prominence of the practice of SGI in northern Ghana, especially in the UER, can be attributed to a number of reasons. Laube et al. (2008) has identified the following:

- Improved infrastructure, such as roads to northern Ghana in the 1990s, attracted traders from the south who purchase vegetables from the area to meet the demand in the south. This provided market opportunities for farmers, especially the young, who concentrate on farming instead of migrating to the south.
- Knowledge sharing among small-scale vegetable farmers has helped improve the spreading of SGI. Young and inexperienced farmers depend on parents and siblings, extended family members, friends and social networks.
- Decline in rainfall and the resultant recurrent drought led to a decline in farming during the rainy season, and thus led to farmers innovating their own irrigation strategies.

Despite the small size of the farms and the low input levels, farmers involved in SGI are able to reap substantial benefits from their farms. In 2006, bucket farmers gained an average profit of more than GHS 150 (approximately USD 160) from their farms. Pump farmers earned considerably more (more than GHS 550 (USD 580). Given the fact that more than 80% of the population of the UER has an overall income below the official poverty line of GHS 90 (GSS 2002), the additional income gained through SGI is substantive. Farmers see SGI to be profitable, and the additional income gained is mainly spent on the household. Pump farmers also invest in means of transport and buildings. SGI is the preferred adaptation strategy with regard to poverty and a changing environment of farmers. While migrating, the main alternative adaptation strategy pursued is increasingly perceived to be less attractive and even dangerous. Results of surveys conducted in the Atankwidi Catchment in northern Ghana showed that 50% of bucket farmers and more than 60% of pump farmers reported that SGI had changed their migration patterns.

Although it is becoming increasingly widespread, crucial information such as the spatial extent of use, physical and economic efficiency, socioeconomic drivers and potential impacts of SGI on groundwater resources remain largely undocumented. This report examines SGI in detail and discusses its performance in the Atankwidi Basin, a subbasin of the White Volta in northern Ghana. The report aims to answer two interlinked research questions:

1. What is the extent of SGI in the Atankwidi Basin?
2. What are the characteristics of the aquifer in the study area, i.e., what is the volume of shallow groundwater that is available for use?

Study Area - Atankwidi Catchment

The Atankwidi Catchment is a tributary of the White Volta Basin and covers approximately 286 km^2. It is located in the UER of Ghana between Navrongo and Bolgatanga with its upper reach in Burkina Faso (see Figure 1). Climatically, it falls within the Sudan-Savanna zone, which is characterized by high temperatures and a mono-modal rainfall distribution with a distinct rainy season lasting from approximately May to September. The long-term mean annual rainfall in Navrongo is 990 millimeters (mm) as calculated from monthly rainfall data for the years 1961-2001 obtained from the Ghana Meteorological Agency. Temperatures are high throughout the year with an average daily maximum temperature of 35 °C and average daily minimum temperature of 23 °C.

The Soil Research Institute of Ghana distinguishes three main soil types in the catchment (Environmental Protection Agency-World Bank 1999). These are: (1) Leptosols, which are predominant along the elevated northern and eastern border, (2) Fluvisols, which are found in the flat terrain to the sides of the main stream, and (3) Lixisols, which covers the rest of the catchment.

The hydrogeology and climate conditions of the catchment are typical for a large part of the Volta River Basin (Martin and van de Giesen 2005). This means that results of studies conducted in this catchment are transferrable to other areas of the basin. The Atankwidi Catchment is one of the areas with the highest groundwater use per square kilometer in the Volta River Basin (Martin 2006). The main aquifer is the regolith aquifer in the weathered zone of granitoids. This hydrogeology is typical for about two-thirds of the area of the Volta River Basin, which are underlain by Birimian rocks. More than 80% of all boreholes in the basin target the weathered rock aquifer (Martin 2006).

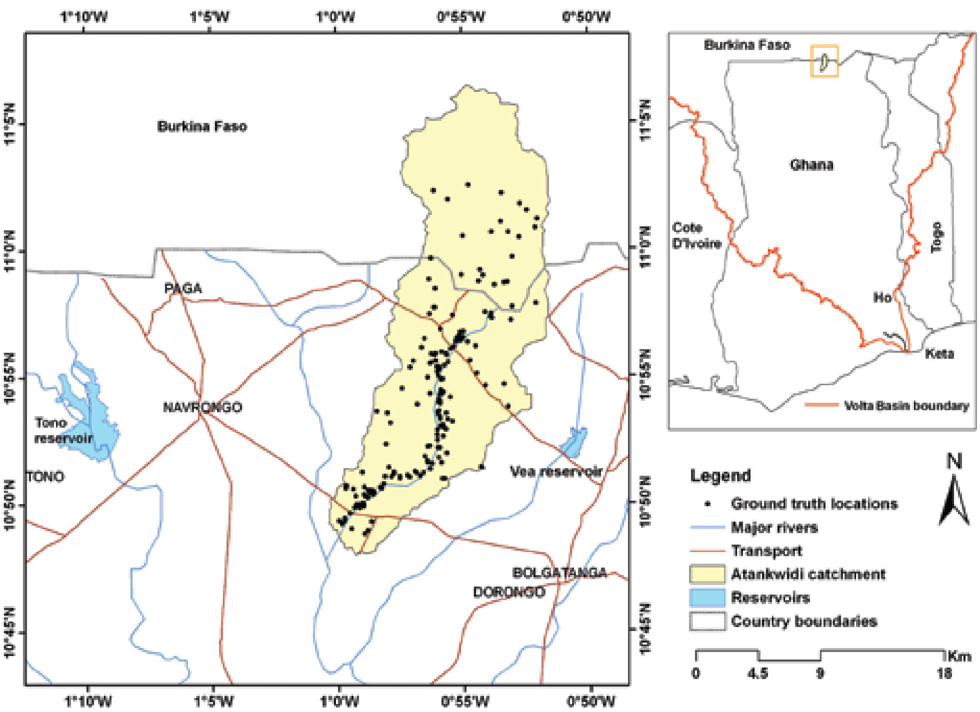

FIGURE 1. Map of the Atankwidi Subbasin showing ground truth locations used in the remote sensing (RS) analysis.

Types of SGI systems

There are many versions of SGI systems observed in Ghana. These include shallow tube well irrigation systems, seasonal shallow wells (i.e., riverine and in-field), permanent shallow wells (lined or unlined) and communal borehole systems. In the Upper West region, a non-governmental organization (NGO) known as ProNet is distributing free manual or rope pumps for abstracting water from shallow groundwater. The farmers can irrigate about 0.69 ha of land with this technology. A detailed description of each type of these SGI systems can be found in Namara et al. (2010).

Methods

Mapping of Areas Under SGI using Remote Sensing

A good documentation of areas under SGI is important for estimating the quantity of water required for irrigation and its possible impacts on groundwater resources in the catchment. Remotely sensed images of the area were used to map these areas in this study. Remote sensing has a major advantage over ground surveying methods (theodolite and global positioning system (GPS) surveys), in that images over large areas can be analyzed in a short time and at a relatively cheaper cost. In addition, remote sensing enables the mapping of inaccessible areas.

A very high resolution QuickBird image, acquired in May 2008, was used as the primary data source for delineating areas under SGI in the Atankwidi Catchment.

Remotely sensed images are affected by the atmosphere, which is the medium through which electromagnetic energy travels. The sun (in the case of passive sensors) sends out electromagnetic radiation, which is reflected off objects on the Earth's surface and the response recorded by sensors mounted on satellites. The intensity of the signal from the sun, as well as that from the objects (to be recorded at the sensor), is often attenuated due to atmospheric absorption while its directional properties are altered by scattering (Mather 2004). Images must, therefore, be preprocessed to correct for any attenuation of the signal recorded at the sensor.

The intensity of the electromagnetic radiation from the Earth's surface is recorded by sensors as digital numbers (DNs) for each spectral band (for multispectral images). The use of raw DNs of images in, especially, quantitative image analysis has been described as inappropriate (Lillesand et al. 2004). DNs are image specific, i.e., they are dependent on the viewing geometry of the satellite at the moment the image was taken, the location of the sun, specific weather conditions, etc. It is, therefore, important to convert the DN values to spectral units. In this study, DNs were converted to spectral units (reflectance) using equations and algorithms presented in Markham and Barker (1986).

Ground Truthing

Ground truth data was collected during the period June 3-13, 2008, for 190 sample sites (see Figure 1 above) covering major irrigated areas (which includes shallow dug wells and dugouts in the riverbed) along the river, rainfed fallows and other LULC classes and its percents in the watershed. The purpose of this ground truthing exercise was to understand the main forms of LULC classes in the area. The intended use of the data was to aid in (1) classification, and (2) for accuracy assessment (i.e., posts classification) - verifying that the results obtained reflect the real situation on the ground.

The adopted approach was to look for contiguous areas of homogeneous classes within which a sample (GPS location) can be taken. For each LULC class identified, 10-40 samples were taken. In addition, two or three photographs of the LULC type at each location sampled were taken. Such photographs eventually prove useful if there is any ambiguity about LULC classes during accuracy assessment.

Unique labels were given to each of the 14 LULC classes identified during the ground truthing exercise. Classes have the flexibility to merge to a higher class or break into a distinct class based on the LULC percentages observed at each location. Figure 1 shows the location of samples gathered in the Atankwidi Catchment.

Image Classification

The QuickBird image was classified to reveal the various LULC classes using the methodology outlined in Thenkabail et al. (2004) and Gumma et al. (Forthcoming). Figure 2 presents the main processes followed.

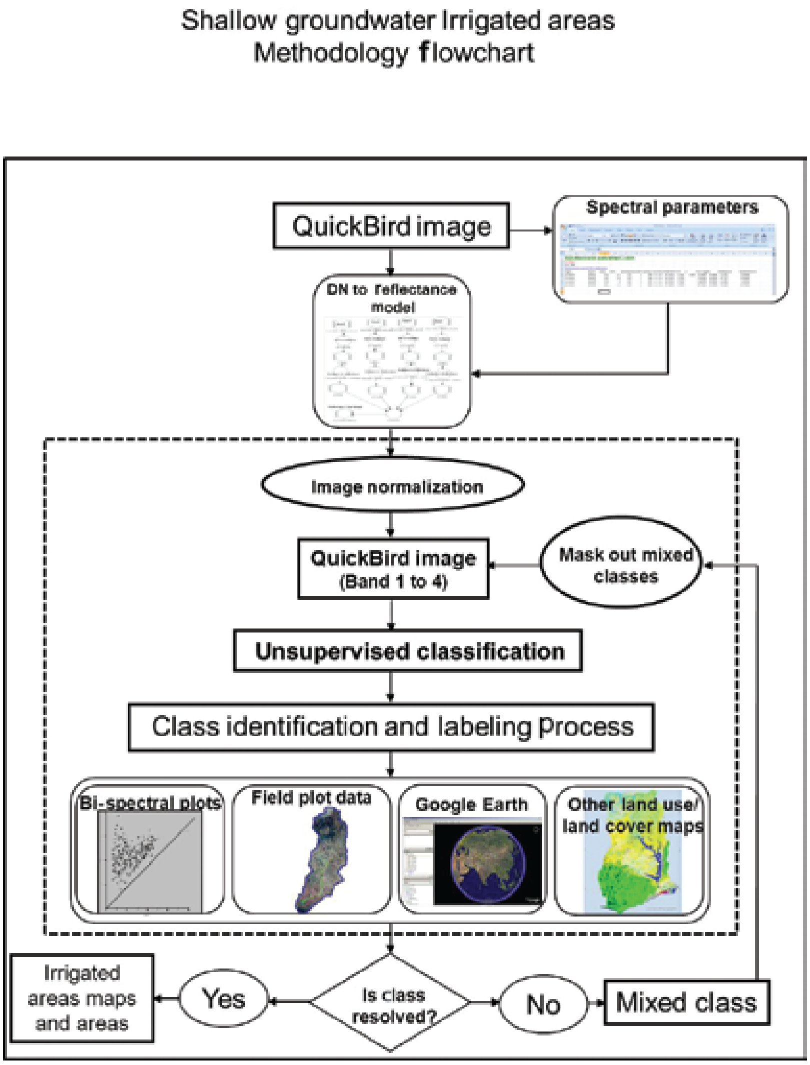

FIGURE 2. Flowchart of processes.

Unsupervised classification using ISOCLASS cluster algorithm (ISODATA in ERDAS Imagine 9.2™) followed by progressive generalization (Cihlar et al. 1998) was, first, used to classify the QuickBird image. With a maximum of 40 iterations and a convergence threshold of 0.99, 40 LULC classes were generated. Use of unsupervised techniques is recommended for large areas that cover a wide and unknown range of vegetation types, and where landscape heterogeneity complicates identification of homogeneous training sites (Achard and Estreguil 1995; Cihlar 2000). The 40 classes obtained from the unsupervised classification were merged using bi-spectral plots, intensive ground truth data (described above) and Google Earth imagery (Gumma et al. Forthcoming; Thenkabail et al. 2005; Tucker et al. 2005). Older Landsat data were used for cloud patches.

Bi-spectral plots. The spectral properties of the classes obtained through unsupervised classification were performed on the megafile using ISODATA statistical cluster algorithm for multidimensional data. The bi-spectral plot for all the classes is obtained by plotting the spectral reflectance of Band 3, Red (Quickbird), on the x-axis and spectral reflectance of Band 4, Near Infrared (Quickbird), on the y-axis. The diagonal line on the resultant graph represents the soil line. The soil line clearly separates the classes with vegetation above the soil line from the classes without vegetation below the line. The classes with similar spectral reflectance fall nearby as a cluster. Such classes may represent the same category with a slight variation in reflection. Classes like water bodies and forest, which have a large variation in vegetation, can be easily identified and labeled.

Google Earth data (http://earth.google.com/) contain increasingly comprehensive image coverage of the globe at a very high resolution of 0.61-4 m, with different seasonal images. These data were used for i) identification and labeling of classes (especially cloud-affected areas), ii) assessing accuracy of irrigated area classes, and iii) verification of identified LULC classes.

Resolving mixed classes: Some classes were locally misclassified and intermixed with neighboring classes, and such misclassified pixels were normally identifiable using ground truth data points where land use types were mapped out in their normal context (Fuller et al. 1998). For example, the "fallow" class mixes with rangelands. Such misclassifications were removed by contextual correction methods (Groom et al. 1996; Thenkabail et al. 2006).

Assessing Accuracy of Results

A qualitative accuracy assessment was performed to check if the area under SGI is classified as irrigated or not, without checking for crop type or type of irrigation. The accuracy assessment was performed using field-plot ground truth data (described above), to derive a robust understanding of the accuracies of the datasets used in this study.

Accuracy assessment provides realistic class accuracies when land cover is heterogeneous and pixel sizes exceed the size of uniform land cover units (Gopal and Woodcock 1994; Thenkabail et al. 2005; Gumma et al. Forthcoming). Groups of 3 x 3 pixels of QuickBird were assigned around each of the field-plot points to one of 6 categories: (1) absolutely correct (100% correct), (2) mostly correct (75% or more correct), (3) correct (50% or more correct), (4) incorrect (50% or more incorrect), (5) mostly incorrect (75% or more incorrect), and (6) absolutely incorrect (100% incorrect). Class areas were tabulated for a 3 x 3-pixel (9 pixels) window around each field-plot point. Using this, a comprehensive accuracy assessment of all 14 classes was made. For instance, if 14 out of 14 QuickBird classes matched with field-plot data, then it was labeled absolutely correct and so on. Table 1 gives the details of this exercise.

TABLE 1. Classification accuracy assessment results based on field plots.

Land use/land cover class	Samples #	Total correct	Absolutely correct	Mostly correct	Correct	Incorrect	Mostly Incorrect	Absolutely correct	Total Incorrect
01. Water bodies	0	100	1.0	0.0	0.0	0.0	0.0	0.0	0
02. Riverbed and bare soils	1	100	1.0	0.0	0.0	0.0	0.0	0.0	0
03. Settlements	0	100	1.0	0.0	0.0	0.0	0.0	0.0	1
04. Barren lands	18	61	0.2	0.0	0.4	0.4	0.0	0.0	39
05. Barren lands mixed with rangelands	10	80	0.6	0.0	0.2	0.2	0.0	0.0	20
06. Rangelands mixed with barren lands	4	81	0.3	0.0	0.6	0.2	0.0	0.0	19
07. Rangelands mixed with fallows, short shrubs	11	88	0.8	0.0	0.1	0.1	0.0	0.0	13
08. Rangelands-rainfed fallows	35	100	1.0	0.0	0.0	0.0	0.0	0.0	0
09. Rainfed-MS[1]-mixed crops	14	100	1.0	0.0	0.0	0.0	0.0	0.0	0
10. Rainfed-LS[2]-mixed crops	12	92	0.8	0.0	0.1	0.1	0.0	0.0	8
11. Irrigated-shallow groundwater-vegetables	70	94	0.9	0.0	0.0	0.0	0.0	0.0	6
12. Short shrubs, trees	5	100	1.0	0.0	0.0	0.0	0.0	0.0	0
13. Savannah, trees, short shrubs	6	94	0.9	0.0	0.0	0.0	0.0	0.0	6
14. Savannah, forest (trees)	4	100	1.0	0.0	0.0	0.0	0.0	0.0	0
	190	92	0.8	0.0	0.1	0.1	0.0	0.0	8

[1] Medium scale

[2] Large scale

Estimating Groundwater Volume

To estimate groundwater volume from the aquifer dimensions, a number of field measurements were made with two different devices. These include electromagnetic profiling and vertical electrical sounding.

Electromagnetic Profiling

Measurements were made to detect fissured zones and thick overburden or weathered zones (regolith), which control shallow groundwater occurrence in the study area. This was carried out using the Geonics EM 34-3 ground conductivity meter. This equipment provides a direct reading of apparent electrical conductivity in the region of the measuring coil using electromagnetic induction as described by McNeil (1980). A 20-m inter-coil separation cable was chosen and the standard 20 m station interval was adopted in this study. Ideally, profiling should have been carried out along well-defined traverses, but this was impossible because the study area was heavily cropped at the time of the survey. Thus, measurements were carried out at irregular intervals and sometimes along curved traverses between ridges and along footpaths. Profiling was carried out along 30 traverses in the study area. Conductivity was measured in both horizontal and vertical dipole modes. The measured conductivity values at approximately 7.6 m and 17.4 m, i.e., in both horizontal and vertical dipole modes, have been plotted against the station intervals along each traverse to give dipole response curves. Figure 3 shows sample electromagnetic dipole response curves at location N 10^{o} 49’ 51” latitude and W 0^{o} 59’ 22” longitude. The horizontal and vertical dipole responses were compared along each traverse to determine the existence of conductance and hence the presence of structures associated with groundwater occurrence. The horizontal dipoles were higher than the corresponding vertical dipoles everywhere, suggesting decreasing conductance with depth and therefore shallow regolith (overburden development). Large variations in apparent conductivity were witnessed, i.e., 14-51 μS cm-^{1} for the horizontal dipole and 6.0-36 μS cm-^{1} for the vertical dipole. The clayey portions show higher conductivity values and hence lower permeability while the more sandy portions show lower conductivity values and thus higher permeability/hydraulic conductivity.

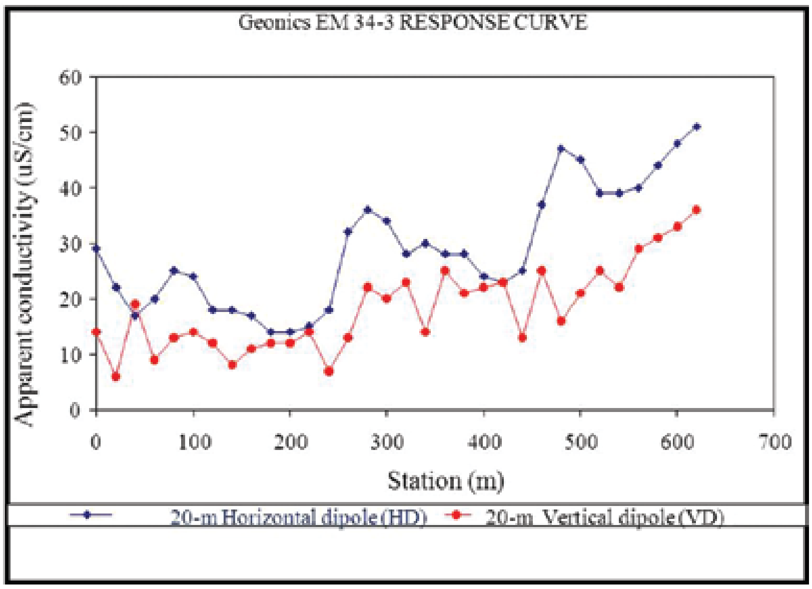

FIGURE 3. Sample of Geonics EM 34-3 response curves (20-m horizontal and vertical electromagnetic dipole responses).

Vertical Electrical Sounding (VES)

VES was conducted at 330 sites in the catchment to determine the depth and thickness of the shallow aquifers. VES points were randomly selected at places where adequate space existed for carrying out the measurement. All points were georeferenced. Data control was carried out by plotting the VES results as the sounding was in progress. Values, which appeared unreasonable, were rejected and the sounding was repeated at the same spot several times as deemed necessary to achieve conformity. Figures 4 and 5 show sample modeled curves created from results of the VES undertaken at the edge and middle of the study area, respectively. The results depict a three-layered structure at each VES point. A low resistivity layer sandwiched between relatively higher resistivity upper and lower layers. In Figure 4, for instance, the soil layer is only 0.6 m thick, and the middle layer which is the saprolite and the zone likely to contain groundwater is only 5.9 m thick and has a resistivity as low as 12 ohm-m, suggesting high argillite content and thus low permeability/transmissivity. On the contrary, Figure 5 indicates a depth profile of 0.8 m of soil layer, saprolite of 10.9 m with moderate resistivity of 50.2 ohm-m, suggesting more sandy overburden and higher groundwater potential at the middle of the catchment than at the edge.

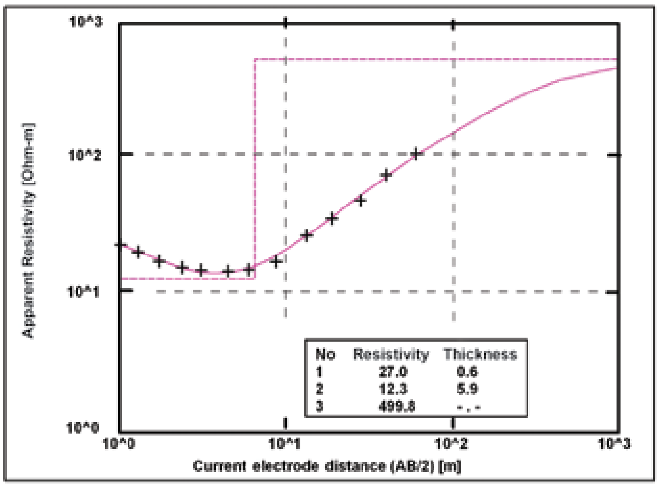

FIGURE 4. Modelled curve for VES at the edge of the Atankwidi Basin.

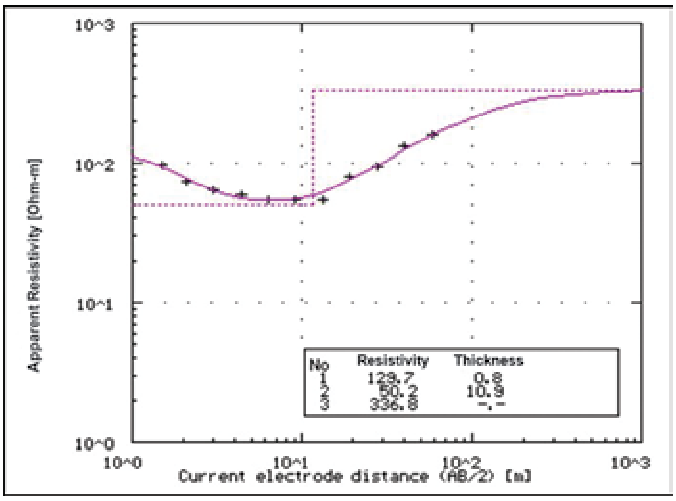

FIGURE 5. Modelled curve for VES at the middle of the Atankwidi Basin.

Generally, the top layer is thin; this is the top dry portion of the regolith (overburden) or the dry soil (collapsed zone). The lower "high resistivity" layer constitutes the slightly weathered bedrock (saprock) or the fresh bedrock. The middle low resistivity layer is the moist part of the regolith (highly weathered zone or saprolite) that constitutes the shallow aquifer (Figure 6). The results indicate that the thickness of the overburden that constitutes the aquifer varies from 2.6 to 13.7 m with the median and mean values of 6.6 and 6.8 m, respectively. The standard deviation is 3.2. The overburden generally has low resistivity. The resistivity of the saprolite is in the range 3.2-55.3 ohm-m with median and mean values of 28.0 and 29.0 ohm-m, respectively, confirming the earlier derivative from the electromagnetic survey that permeability and transmissivity values could be low. In other words, the lower the resistivity of the saprolite (overburden) the higher the clay content, higher the porosity, and lower the permeability and transmissivity. Figure 7 shows the conceptual model along one of the traverses.

Hydraulic Conductivity and Porosity

Determination of hydraulic conductivity can be problematic due to parameter differences over several orders of magnitude across the spectrum of sediments and rock types. The parameter may also vary significantly in space, even with seemingly minor changes in sediment characteristics. Hydraulic conductivity is also affected by the properties of the fluid being transmitted and the porous medium. Hydraulic conductivity is also scale-dependent and direction-dependent. Hydraulic conductivity cannot be directly measured but can be inferred from field, laboratory or modelled data.

Hydraulic conductivity (K) can be estimated by particle size analysis, using empirical equations relating either "K" to some size property of the sediment (Vukovic and Soro 1992; Alayamani and Sen 1993; Duwelius 1996; Odeng 2007). In this study, the Vukovic and Soro (1992) method was adopted. Vukovic and Soro (1992) analyzed empirical methods from former studies and presented a general formula:

$$K = \frac{g}{v}.C.f\ (n).\ d_e^{\,2} \quad (1)$$

where: K = hydraulic conductivity; g = acceleration due to gravity; v = kinematic viscosity; C = sorting coefficient; $f(n)$ = porosity function; and d_e = effective grain diameter. The values of "C","$f(n)$" and "d_e" are dependent on the different methods used in the grain-size analysis. According to Vukovic and Soro (1992), porosity *(n)* may be derived from the empirical relationship with the coefficient of grain uniformity *(U)* as follows:

$$n = 0.255.(1+0.83^{U}) \quad (2)$$

where: U is the coefficient of grain uniformity and is given by:

$$U = \frac{d_{60}}{d_{10}} \quad (3)$$

Here, d_{60} and d_{10} in the formula represent the grain diameter (in mm) for which, 60% and 10% of the sample, respectively, are finer than the remainder of the sample.

The Equation (2) proposed by Vukovic and Soro (1992) was used to compute porosity *(n)* for all eight soil samples taken from selected hand-dug wells. The results of the grain size analysis based on the above methods give an average grain size of 0.26 or 26%.

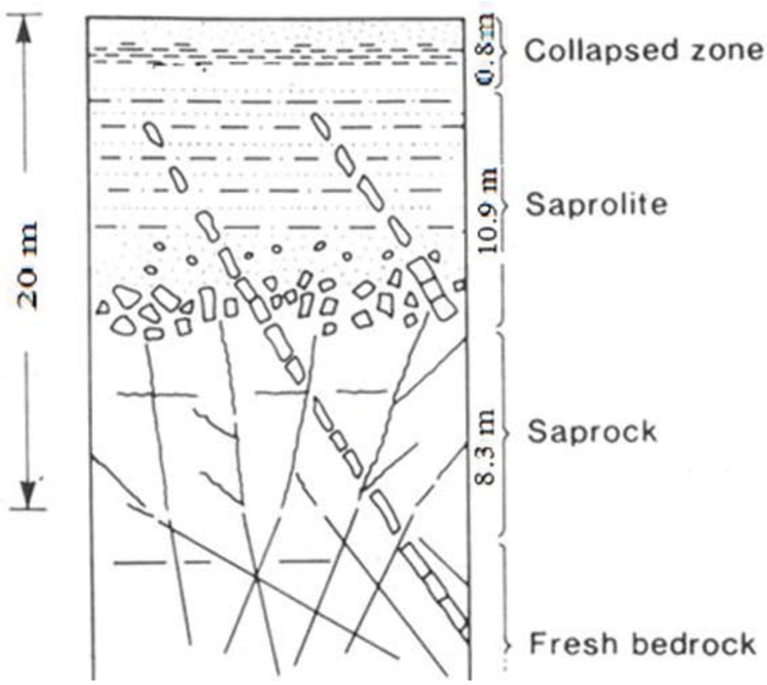

FIGURE 6. Schematic weathered profile as delineated by modelled curve for VES at the middle of the Atankwidi Basin (*source:* modified after Wright 1992).

- Collapsed (soil) zone: This may show marked lateral variation but is generally sandy on watershed areas with illuviated clay near the base.
- Saprolite is derived from in situ weathering of the bedrock but is disaggregated. Permeability may probably increase at lower levels due to lesser development of secondary clay minerals.
- Saprock is weathered bedrock. Fracture permeability is generally increased as a result of weathering (compared with fresh bedrock) unless filled in by illuviated clay minerals (after Wright 1992).

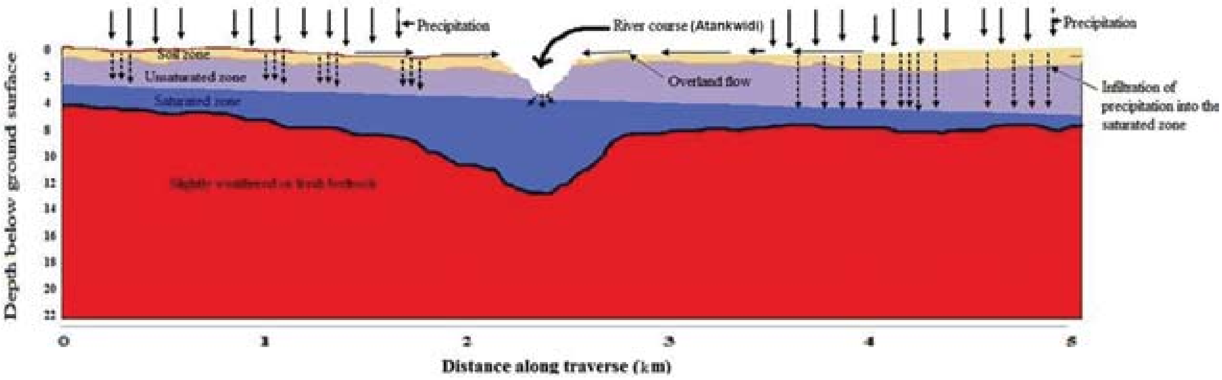

FIGURE 7. Conceptual model of a shallow aquifer in the Atankwidi Subbasin.

Estimation of Cross-sectional Area

The cross-sectional area of the catchment was determined by dividing it into five sections, almost perpendicular to the length of the river channel (Figure 8). Minute trapeziums were created along each section (Figure 9). The lengths of the parallel sides of the trapeziums are the depths between the water table and the bedrock, derived from the electromagnetic profiling and VES measurements. Figure 8 shows the location of the five cross-sections in the catchment. The cross-sectional area was computed using Simpson's rule.

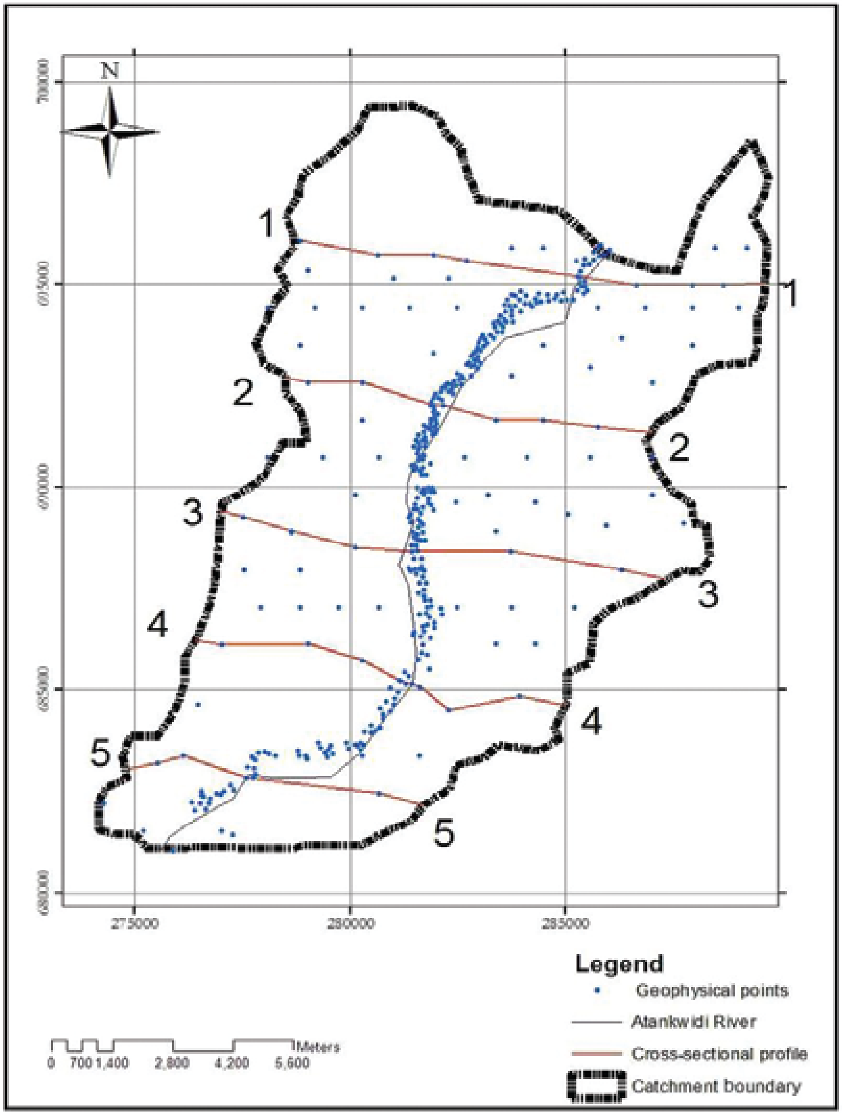

FIGURE 8. Location of five cross-sections in the catchment.

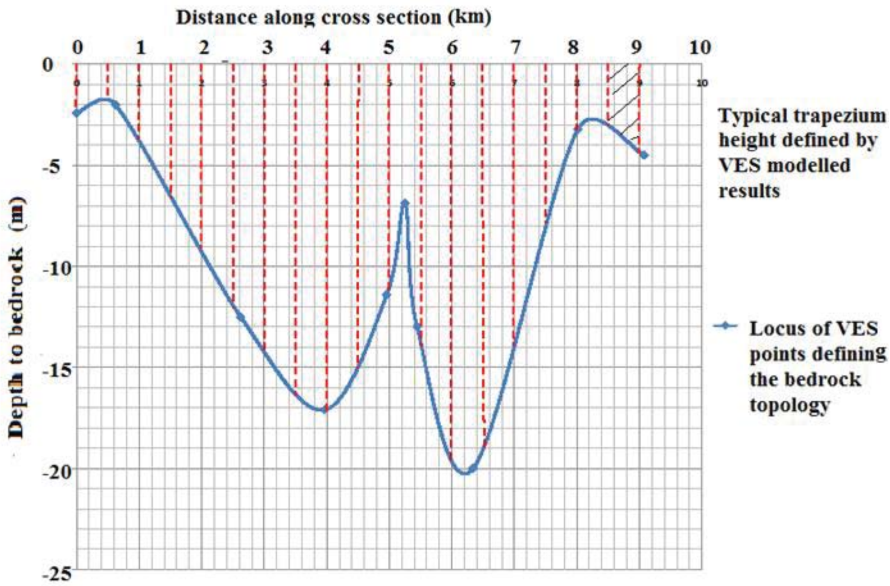

FIGURE 9. Trapeziums formed out of the locus of the modeled VES values of the bedrock topology.

An estimate of the volume of water that can be stored in the underlying aquifer in the Atankwidi was, thus, calculated by multiplying the average cross-sectional area (see Table 2) of the aquifer along the selected traverses with the porosity and length of the basin. The length of the basin was found to be 20.415 kilometers (km).

TABLE 2. Volume of water stored in the Atankwidi aquifer.

Section	Area (m^2)	Groundwater storage
1-------1	80,066.67	Length of catchment = 20415 m
2-------2	51,440.00	Volume = Average porosity x length x average sectional area
3-------3	66,400.00	
4-------4	88,066.67	Volume = 0.262401 x 20415 x 69,214.67
5-------5	60,100.00	
Average	69,214.67	Volume = 370,777,191.2 m^3 (370 Million Cubic Meters ((MCM))

Results and Discussion

Status and Dynamics of Areas Under SGI

Figure 10 shows the results of the remote sensing analysis to delineate areas under SGI. The results were validated with field data taken during a ground truthing exercise, and an overall accuracy of 92% was obtained (Table 1). As already noted, other LULC types other than areas under SGI were also mapped. Overall, 14 LULC classes were identified and mapped in the Atankwidi Subbasin.

Results indicate that class 11 (SGI) is practiced on a land area of 387 ha (1.4%), rainfed agriculture on 15,638 ha (54.7%); with the remaining being under other LULC types. Table 3 gives details of these classes and the land area under each class. It is clear from the results that the importance and practice of SGI actually increases along the river, since the importance of dry season agriculture for increasing food production leads to agricultural development in these areas.

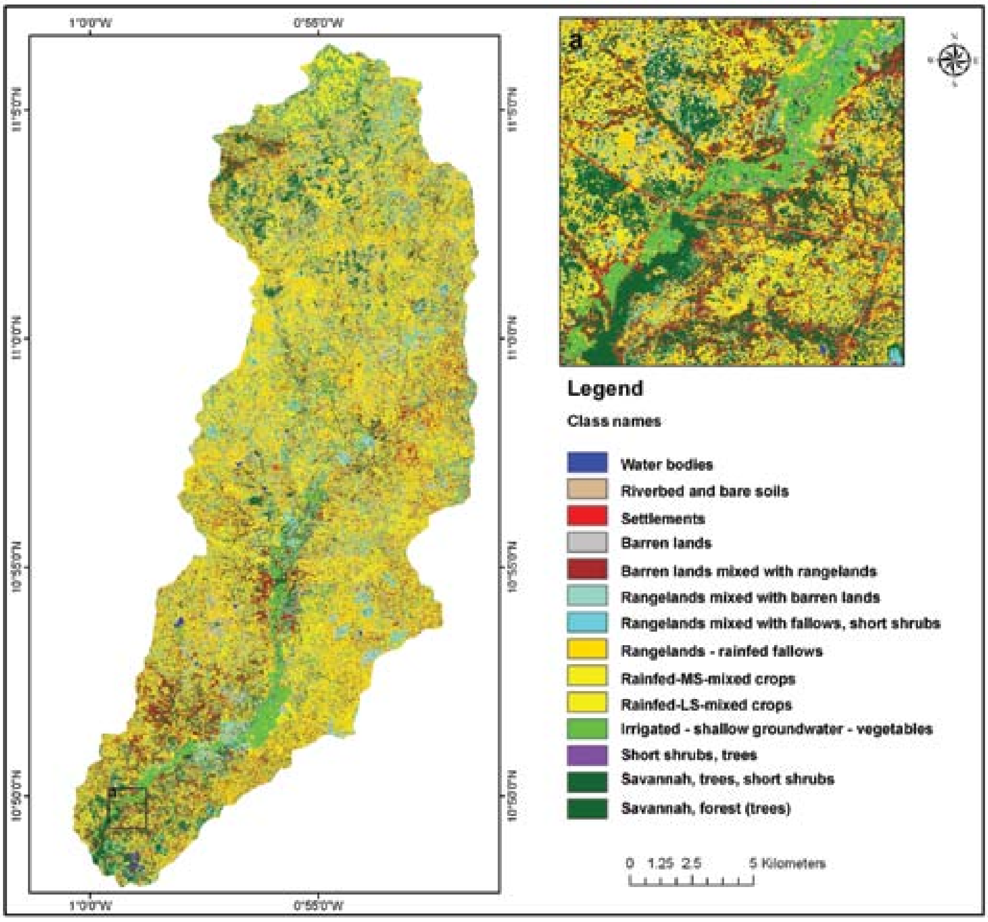

FIGURE 10. Land use/land cover map of Atankwidi Catchment (May 2008).

TABLE 3. Land use/land cover areas and their percentage coverage.

Class no.	Land use/land cover	Area (ha)	% area
1	Water bodies	31.82	0.1
2	Riverbed and bare soils	116.58	0.4
3	Settlements	104.96	0.4
4	Barren lands	3,014.16	10.5
5	Barren lands mixed with rangelands	2,852.02	9.9
6	Rangelands mixed with barren lands	873.19	3.0
7	Rangelands mixed with fallows, short shrubs	2,079.77	7.3
8	Rangelands-rainfed fallows	11,410.77	39.9
9	Rainfed-MS[1]-mixed crops	1,712.45	6.0
10	Rainfed-LS[2]-mixed crops	2,515.59	8.8
11	Irrigated-shallow groundwater-vegetables	387.23	1.4
12	Short shrubs, trees	64.42	0.2
13	Savannah, trees, short shrubs	1,578.62	5.5
14	Savannah, forest (trees)	1,891.07	6.6
		28,632.65	100.0

[1] Medium scale

[2] Large scale

Irrigated plots in the study area range from 1 to 20 ha along the river stretch (van den Berg 2008). Farmers identify suitable areas for irrigation based on their local experience of the availability of water in the area for dry season farming. They derive this experience (of knowing where there's enough water) from their fathers, brothers or friends, or by learning from other farmers who already apply SGI. In a study, van den Berg (2008) interviewed 30 farmers in the catchment. He found out that the sizes of the irrigated fields vary from 200 to 900 m^2, with three exceptionally large fields of 1,045 m^2, 1,373 m^2 and 3,350 m^2, with an average field size of about 600 m^2 (i.e., apart from the exceptionally large fields). Though farmers are willing to cultivate larger areas, they are mostly constrained by lack of finances to purchase agricultural inputs. Other farmers also indicated that the land allotted to them by their landowners limit their farm sizes. These farmers are unable to rent land elsewhere because (1) landowners will not rent out lands with good soil and reliable access to water, (2) in cases where landowners want to rent out, farmers cannot afford to pay the rent requested by landowners (van den Berg 2008). These reasons may have accounted for the extremely low percentage of irrigated areas, as compared to rainfed areas.

Although the above results indicate that areas under SGI form a small percentage (1.4%) of LULC types in the catchment, previous work (Laube et al. 2008; Schindler 2009), coupled with results obtained in this study, indicate that areas under SGI increased dramatically between 2005 and 2008. A supervised classification (using the Mahalanobis Distance algorithm) of a QuickBird image of the Atankwidi Catchment identified irrigated areas in February 2005 (Rebelo Forthcoming). Visual analysis was used to generate training data for five LULC classes – bare soil, savanna vegetation, burned vegetation, trees and irrigated areas. While a detailed ground dataset are not available for 2005, data are available for three farm locations which were irrigated at the time of the analysis. The location of each of these farms and the irrigated plots within these at the time of image acquisition were compared to the classification results, with all three correctly identified as irrigated land.

Results from the analysis revealed that an area of approximately 60 ha was under SGI in February 2005. Comparing this figure to the 387 ha obtained in May 2008 suggests a tremendous increase (factor of 6) in the area under SGI in the Atankwidi Catchment. Although authors acknowledge the difference in methodology (with 2008 following a more detailed approach than that of 2005), the difference in areas suggest, at least, some kind of increase in areas under SGI between 2005 and 2008. It is important to note that February represents the peak of the harvesting period in Atankwidi whereas in May, very few crops will still be awaiting harvesting. This means that the actual irrigated area in 2008 may have been much larger than what was recorded (387 ha), which would have suggested an even bigger increase in areas under SGI between the dates when the two images were accessed. This increase can be attributed to a number of reasons: (1) an increased awareness of the residents of Northern Ghana that migrating to the south during the dry season in search of menial jobs is not the solution and that dry season farming could be a real source of livelihood (Laube et al. 2008), (2) the change in hydrology due to the 2007 floods (van den Berg 2008), and (3) the reopening of the tomato factory at Pwalugu in 2007, which may have motivated farmers to increase their area of cultivation. Figure 11 shows examples of areas within the river channel that have witnessed increases in the area under SGI between 2005 and 2008.

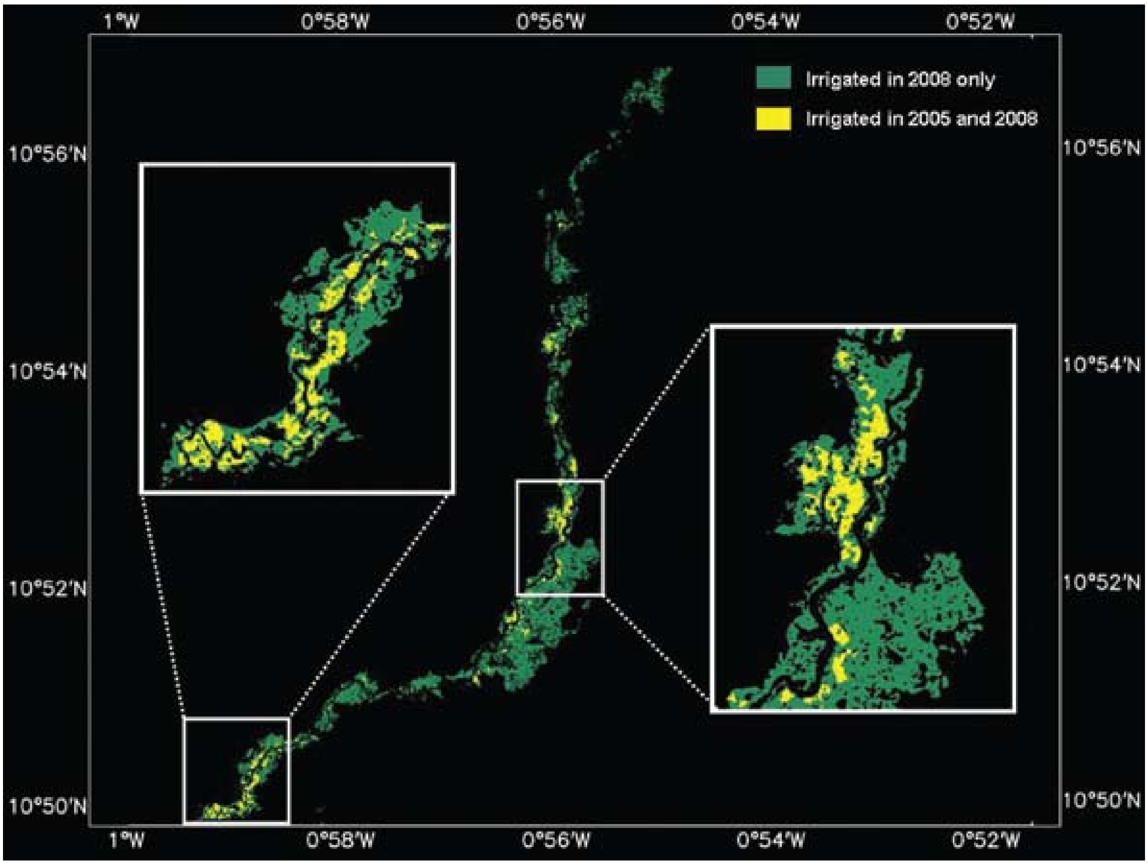

FIGURE 11. Irrigated areas in the Atankwidi Catchment in February 2005 and 2008 (yellow), and only in May 2008 (green) (*Source:* Rebelo Forthcoming).

Potential Volume of Groundwater in the Shallow Aquifer

The underlying aquifer in the Atankwidi Catchment was found to be capable of storing about 370 MCM of water per year (see Table 2 for more details). It must be stated that this includes soil moisture. Access to this groundwater for SGI is mainly through the digging of shallow wells. Farmers dig shallow wells along the Atankwidi River for dry-season farming (irrigation). The typical distance between wells and the riverbed is 15 to 500 m. The location suitable to dig a shallow well is purely based on the farmer's local knowledge of the area. Farmers use trial and error methods to find suitable areas where one can get good water yield. Van den Berg (2008) noted that shallow wells are dug from late September to late October. Farmers with fields close to the river wait till the river stops flowing in October, and farmers further away start digging earlier. Wells are closed at the end of the dry season to prevent animals falling into them or rains eroding the area close to the well, resulting in well instability. Typically, there are 2 to 3 wells on smaller farms whereas larger ones have between 3 and 5 wells. The intensity of use of these wells during the dry season causes a lowering of the water levels each day, but fortunately they collect (regain) enough water overnight for the next day's irrigation. Farmers will periodically deepen their wells in order to harvest more water for irrigation. Most of the farmers deepen their wells 1 to 3 times during the dry season for approximately 0.3-0.5 m per time (van den Berg 2008).

In a typical planting season (for tomatoes), irrigation by shallow groundwater is essential during two main stages - the first and flowering stages (see Table 4 for the various stages). In the "first" stage, most of the farmers do not irrigate for one or more days after an irrigation round and carry out other activities instead. The flowering stage, on the other hand, requires more water. The amount of irrigation water that is applied is increased in this stage, and almost all farmers irrigate every day. Van den Berg (2008) noted that "farmers need 1 to 4 days to irrigate in the first stage, with a mean of 2.5 days and 2 day rest." One bucket of water is applied to 1 to 3 crop gutters with a mean of 6.5 liters per crop gutter. In the flowering stage farmers typically need 2 to 5 days to irrigate, with a mean of 3.2 days and 0.5 day rest. They apply one to two buckets per crop gutter with a mean of 14 liters per crop gutter in this stage. The irrigation data is converted to water use in liters per day per square meter ($l/d/m^2$), and 1.0-4.6 $l/d/m^2$ is used for the first stage with a mean of 2.2 $l/d/m^2$, whereas the water use is 3.0-8.9 $l/d/m^2$ in the flowering stage with a mean of 5.5 $l/d/m^2$. Table 5 summarizes the volume of water required in the two stages.

TABLE 4. Stages in the cultivation of tomatoes in the Atankwidi Catchment (*Source:* van den Berg 2008)

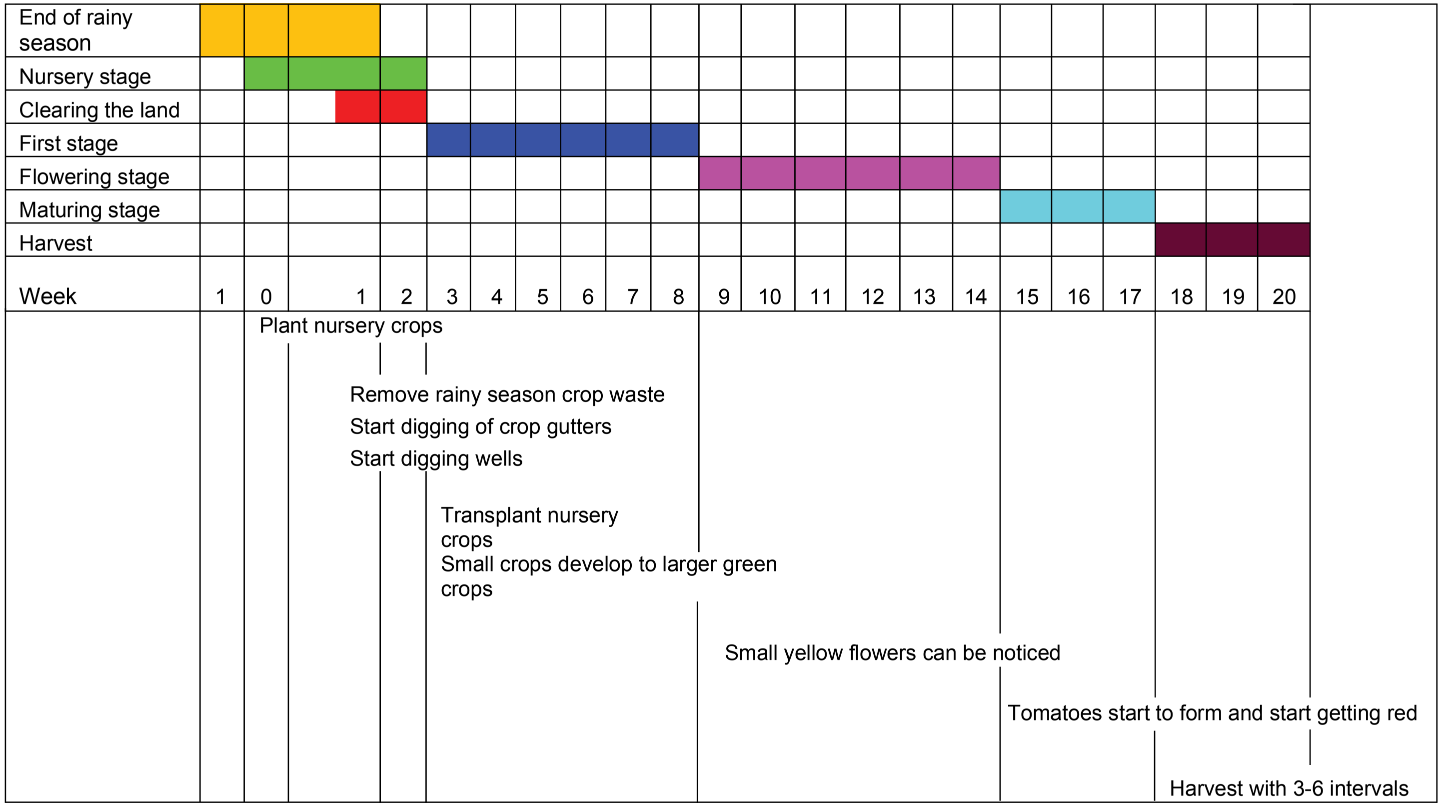

TABLE 5. Volume of water required in a typical planting season (*Source:* van den Berg 2008).

	Range	Mean
First stage		
Number of days for irrigation	1 - 4 days	2.5 days
Rest after an irrigation interval	0 - 3 days	2 days
Irrigation volume	1.0 - 4.6 l/d/m^2 of irrigated field	2.2 l/d/m^2
Flowering stage		
Number of days for irrigation	2 - 5 days	3.2 days
Rest after an irrigation interval	0 - 2 days	0.5 days
Irrigation volume	3.0 - 8.9 l/d/m^2 of irrigated field	5.5 l/d/m^2

Comparison of figures in Tables 2 and 5 indicate that groundwater resources in the underlying aquifer are capable of sustaining shallow groundwater irrigation in the Atankwidi Basin if all conditions remain the same.

Conclusions and Recommendations

The methodology developed for this study, which is based on the use of high resolution images, has proven to be a very good tool for delineating SGI. It could easily be used to assess the extent of SGI in the White Volta Basin. However, the limiting factor here is the high cost of these images. Combining images of a very high resolution with images of a medium resolution (e.g., LandSat-TM) could be the way forward to assess the existing as well the potential of SGI in the White Volta Basin.

Comparison of two QuickBird images of the Atankwidi watershed taken in February 2005 and May 2008 show an increase in areas under SGI. The increase witnessed may not reflect the true reality because the time the two images were taken coincides with different phases of the cropping season. The February 2005 image is at the peak of the tomato harvesting period and, more generally, by April most of the fields are harvested, and land preparation for the rainfed cropping season starts. Very little cropping and irrigation is done in May. Possible reasons for such an increase have been discussed above.

Mapping of the Atankwidi aquifer show the potential storage volume of approximately 371 MCM (370,777,191 m^3) is more than the estimated total volume applied for irrigation (5.5 l/d/m^2) and, thus, more land can be irrigated if appropriate drilling techniques are used. However, one of the limiting factors is the high intensive labor required for manually digging wells during the cropping and refilling them with sand before the rainy season starts to avoid accidents when most of the low areas are flooded.

Tomatoes need in the order of 0.5-1 m of water per growing season (estimated using CROPWAT, a decision support tool developed by the Land and Water Development Division of the Food and Agriculture Organization of the United Nations (FAO)) and for sustainable irrigation practices, which means that in order to meet this water demand the rainfall recharge needed should create a rise in the water table of 1.5-4 m during the wet season (Mdemu et al. 2010) if it is assumed that groundwater is derived locally and that the contribution from lateral inflows are negligible. It is hypothesized that this can only occur if the area is flooded for an extensive time. With a recharge rate of flooded land of 2 cm/day, 50 days will result in the required groundwater recharge. Further data gathering is needed to measure the recharge rates in the area around the Atankwidi during the wet season and to map the extent of the flooded area.

The application of water for the farmer adopting SGI is rather efficient, despite being labor intensive. The farm adopting SGI applies the water directly onto the crops in a small crop gutter, and hence no water is lost to infiltration in gullies. Also, evaporation losses from the wells are negligible. The water use among farmers, however, shows a large variation. To improve water use in respect to durability of water in the aquifer, a more equal amount of water among farmers is advisable. On the other hand, it might be interesting to study if differences in water use lead to differences in productivity or to find out if farmers have other legitimate reasons to use more or less water.

SGI, as practiced by farmers in the Atankwidi watershed, is rudimentary and requires a lot of labor for digging and watering the crops. Sustainability and profitability of SGI could be obtained if improved smallholder irrigation technologies such as tube wells are introduced in the study area. This could considerably reduce the time spent on digging and will also lower the risk of failure. The impact of SGI on livelihood security as well as its sustainability of the aquifer will be addressed in the modeling exercise and the socioeconomic survey recently conducted in the basin (Namara et al. 2010).

Since the geology conditions and farmers' irrigation practices in the Atankwidi Basin are similar to those in different parts of the White Volta Basin, it may be possible that any improvement in groundwater development and application techniques could be out-scaled to a larger area. Recent drilling of tube wells based on the outputs of this study and introduction of drip irrigation by International Development Enterprises (IDE) in the Atankwidi watershed could lead to significant improvement in water availability and productivity, and hence the livelihoods of thousands of farmers in northern Ghana.

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