Quantification of surface and groundwater resources in the Anyari watershed of the Upper East Region in Ghana

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Through action research and development partnerships, Africa RISING will create opportunities for smallholder farm households to move out of hunger and poverty through sustainably intensified farming systems that improve food, nutrition, and income security, particularly for women and children, and conserve or enhance the natural resource base.

The three regional projects are led by the International Institute of Tropical Agriculture (in West Africa and East and Southern Africa) and the International Livestock Research Institute (in the Ethiopian Highlands). The International Food Policy Research Institute leads the program's monitoring, evaluation and impact assessment. http://africa-rising.net/

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Acronyms

Africa RISING	Africa Research in Sustainable Intensification for the Next Generation
BH	Borehole
HDW	Hand-dug Well
ICOLD	International Committee of Large Dams
IFPRI	International Food Policy Research Institute
IITA	International Institute of Tropical Agriculture
ILRI	International Livestock Research Institute
IWMI	International Water Management Institute

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Executive summary

Poverty reduction is a key objective of most African countries, where agriculture is the main employment for most inhabitants. The overall aim of the Africa RISING Program is to transform agricultural systems through sustainable intensification.

Tekuru and Nyangua communities located in the Anyari Catchment of the White Volta Basin were chosen for the detail study of the groundwater and surface water resources. Groundwater resources were estimated using the pumping test for shallow wells and boreholes located in Tekuru and Nyangua. Streamflow values for the Anyari stream were used in estimating the surface water resources. The results obtained from the groundwater and surface water compare to those of a previous study conducted around the study area.

The study estimated current groundwater irrigation to be around 500 ha and sustainable potential irrigation for groundwater resources in the Ghana section of the Anyari Catchment at 4500 ha. Sustainable groundwater irrigation potential is highly dependent on the annual recharge of 6% of annual rainfall. During the dry season, there is limited surface water available for irrigation; this calls for the development of small reservoirs to support surface water irrigation in the catchment. The current surface water irrigation in the catchment is about 50 ha. It is estimated that harvesting just 10% of the runoff using dams, dugouts, and underground tanks can lead to an expansion of the irrigable area by 1750 ha.

Irrigation in Anyari can be upscaled to about 6250 ha in the Ghana portion of the catchment and this can lead to a 0.01% reduction in the streamflow to Akosombo. The potential irrigable area from groundwater sources is however sensitive to groundwater recharge and abstraction rates. The study makes recommendations for improved irrigation efficiencies and preservation of wetlands as key to upscaling and sustaining groundwater irrigation.

Introduction

The Africa Research in Sustainable Intensification for the Next Generation (Africa RISING) program is being implemented in three regional blocks of Africa (West, East, and Southern Africa). The three regional projects are led by the International Institute of Tropical Agriculture (IITA) (in West, East, and Southern Africa) and the International Livestock Research Institute (ILRI) (in the Ethiopian Highlands). The International Food Policy Research Institute (IFPRI) leads the program's monitoring and evaluation component.

The overall objective of Africa RISING is to transform agricultural systems through sustainable intensification. The program seeks to create opportunities for smallholder farm households to move out of hunger and poverty through sustainably intensified farming systems that improve crop yield, food, nutrition, and income security, particularly for women and children, and conserve or enhance the natural resource base.

The International Water Management Institute (IWMI) is leading activities under this project on the testing of small-scale irrigation options for dry season vegetable production in Tekura and Nyangua communities located in the Upper East Region of Ghana. One key activity is to study the water availability in these communities to implement dry season farming.

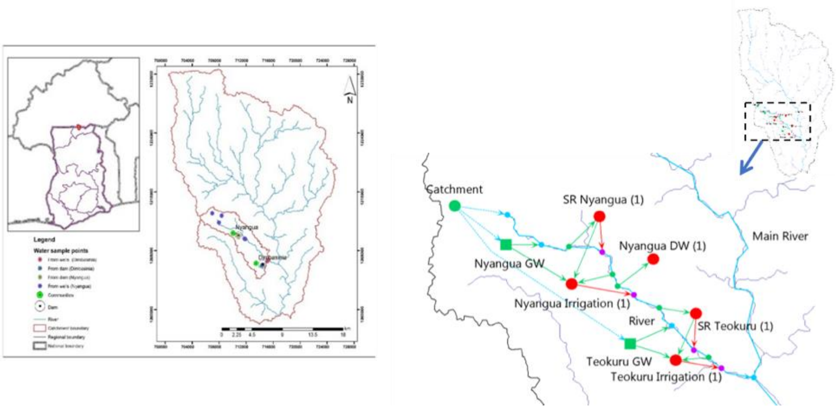
Project objectives and scope of work

The objective is to assess the feasibility of dry season vegetable production and supplementary irrigation of cereal-legume rainfed crops in Tekuru and Nyangua communities in the Upper East Region of Ghana. A major component of the study includes the quantification of surface and groundwater resources in the watershed. This will lead to a better understanding of water availability in these communities to implement dry season farming.

The scope of work included:

1. Estimating groundwater recharge
    - Literature review
2. Estimating groundwater storage
    - Mapping wells and well characteristics
        - Estimating depth (shallow/deep)
        - Water quality
        - Estimating water yield
        - Current use (type and amount)
        - Estimating groundwater availability for dry season irrigation
3. Estimating surface runoff
    - Collecting rainfall and evaporation data for reference period
    - Catchment characteristics
        - Land use
        - Soil type
        - Slope
        - Infiltration estimates based on these characteristics
    - Analyze discharge
4. Surface water storage (mapping reservoirs and dugouts)
    - Estimating capacity
    - Determining water availability during the dry season (time of drying up)
    - Estimating water use (type and amount)
    - Estimating surface water availability for dry season irrigation

Study area



Legend: red dots are demand nodes; green dots are catchment water sources, green boxes are groundwater sources; GW denotes groundwater; SR denotes small reservoirs and DW denotes domestic water demand.

Figure 1. Anyari catchment, local study area, and schematic of water allocation

The Anyari Catchment is located in the White Volta Sub-basin and has an area of 542 km^2 with 253 km^2 (≈47%) of this area within Ghana (Kadyampakeni et al. 2017) (Fig 1). The downstream end of the catchment is located in the Upper East Region of Ghana and the upstream located in the Southern part of Burkina Faso. The catchment is located in one of the poorest regions of Ghana with its inhabitants mainly depending on subsistence agriculture with two cropping systems (crop rotation and intercropping within the year) mostly on Lixisols (Kadyampakeni et al. 2017). The African RISING Project selected two neighboring communities; Tekuru and Nyangua communities in the Upper East Region of Ghana, for the detailed study. The two communities are about 1 km apart and grow cowpea, groundnut, maize, millet, pepper, rice, sorghum, tomato, and other leafy vegetables with the vegetables grown mainly in the dry season (November to March) (Kadyampakeni et al. 2017). The catchment receives significant rainfall of about 890 mm from the months of April to September (Fig. 2).

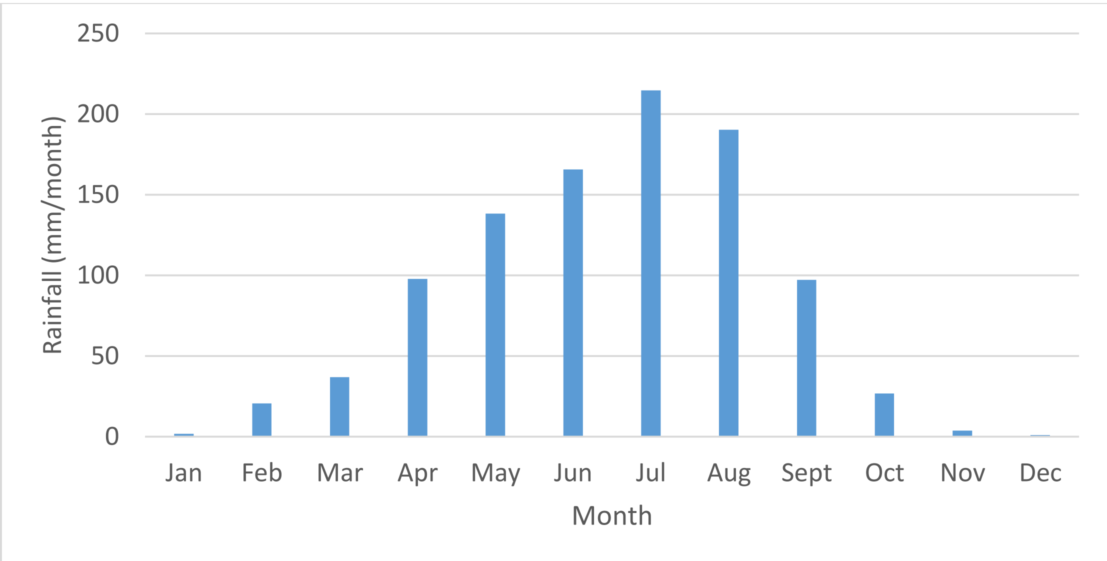
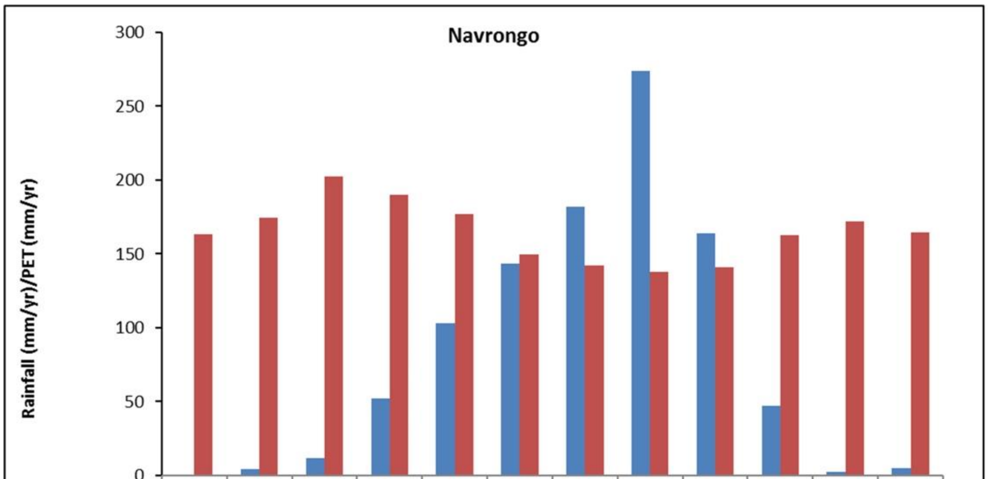


Figure 2. Average monthly rainfall for the Anyari Catchment (1960–2007).

Maximum temperature ranges between 32 °C and 41 °C within the year with March being the hottest. Potential evapotranspiration and rainfall data in the study area (Fig. 3) show that there are only three months in the year with surplus rainfall (i.e., rainfall is higher than potential evapotranspiration); other months have deficits. The maximum potential evapotranspiration (202 mm/month) in the year occurs in March which is also in the dry season. There is limited rainfall in the dry season with high potential evaporation. The study area thus requires substantial amounts of water for dry season irrigation. It also implies that there is the need to store water for dry season irrigation.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rainfall	0	5	12	52	103	143	182	274	164	47	2	5
PET	163	174	202	190	177	150	142	138	141	163	172	164

Figure 3. Long-term average monthly rainfall and potential evapotranspiration in the catchment using data from Navrongo (Source: Kadyampakeni et al. 2017).

A literature review enabled the identification of projects and reports with similar objectives that were carried out in the study area. This was necessary to help in obtaining vital information that could not be obtained within the study period but was necessary in achieving the study objectives. The literature review, presented in this section, looks at studies on groundwater estimation, surface water estimation, and dry season irrigation within the Anyari Catchment and other nearby catchments in the White Volta Sub-basin.

Groundwater estimation

The Anyari Catchment has different types of groundwater irrigation systems. The two major sources of groundwater irrigation are shallow groundwater (5–10 m deep) and deep groundwater (30–60 m deep). Deep groundwater irrigation is not common in Anyari; deep wells are mostly used for domestic water supply instead. Deep wells for irrigation are now being introduced by non-governmental organizations (NGOs) and development partners. The Africa RISING project recently developed six deep wells for irrigation in the study area. The predominant groundwater irrigation is the shallow groundwater which is of different types: permanent shallow wells, temporal shallow wells, and riverine alluvial dugouts (Ofosu 2014). There are permanent shallow wells (Fig. 4) which are lined. These wells are usually developed by landowners on their compound farms and are used for both domestic and irrigation purposes. They are located in areas of high water table. Another type of shallow groundwater irrigation is the temporal shallow wells (Fig. 5), which are located along the stream and are mostly developed by farmers who rent the field for dry season irrigation. As part of the rental agreement, the farmers are not supposed to put up any permanent infrastructure, hence the farmers fill up these wells at the end of the irrigation season, thus the name temporal shallow wells. The third type of shallow groundwater is the riverine alluvial dugouts (Fig. 6), which are found in the river beds. They are developed by farmers who pump the water from the river during the onset of the dry season for irrigation and decide to dig into the river bed when the water streams dry up in the course of the season, thereby creating alluvial shallow wells in the river beds.

Figure 4. Permanent shallow well.

Figure 5. Temporal shallow well.

The quantity of groundwater available for sustainable irrigation agriculture is key to the development and upscaling of irrigation. Groundwater estimation includes the recharge rate and the available storage. A study (Martin and van de Giesen 2005) was conducted in the Volta Basin and within the Atankwidi Catchment (adjacent the Anyari Catchment) of the White Volta Basin to estimate the groundwater availability. Martin and van de Giesen's (2005) study on the spatial distribution of groundwater production and the development potential in the Volta River Basin of Ghana and Burkina Faso provides a general outlook of the groundwater potential in the Upper East Region of Ghana. In their study, they observed that, groundwater utilization in the basin is still less than 1% of groundwater recharge. They also observed that around the borders of Ghana and Burkina Faso where the Anyari Catchment is located, the estimated groundwater recharge is about 3.7% of annual rainfall. In their recommendations, Martin and van de Giesen (2005), noted that to ensure the sustainability of groundwater resources development, long-term monthly monitoring of groundwater table is highly necessary.

Figure 6. Riverine alluvial dugout.

Even though the Anyari Catchment has not experienced any direct groundwater study, the groundwater recharge study of Martin (2006) on the Atankwidi Catchment can be of immense benefit to any groundwater assessments in the Anyari Catchment. This is because the Anyari and Atankwidi are neighboring catchments within the White Volta Sub-basin. Martin (2006) observed that the recharge rates vary considerably between wet and dry years and between locations, with a range of 2 to 13% of annual rainfall. Martin (2006) also observed that the main recharge areas are along the river banks/wetlands and occur mainly during the flood peaks. The long-term recharge rate was approximately 6% of average annual rainfall (Obuobie, 2008).

Not much has been done on the groundwater development potential of the catchment. Groundwater development potential is usually understood as the expected success of groundwater resources exploitation. It is often expressed in terms of expected borehole yields (Dapaah-Siakwan & Gyau-Boakye 2000) or the expected yield per unit of draw-down (Darko & Krasny 2003). These definitions are used as a guide in estimating the groundwater development potential of the Anyari Catchment.

Surface water estimation

The Anyari Catchment which is part of the White Volta Sub-basin, has a total area of 542 km^2. According to Ofosu (2011), runoff generation in semiarid areas typically follows a distinct pattern. Initial rains at the commencement of the rainy season wet up the soil that is dried out after the long dry season. These rains produce very little runoff. Only after the soils are above field capacity does water flow from the watershed to streams. Van de Giesen et al. (2001) showed that the rainfall runoff coefficient for the Volta Basin varies between 7% and 57%. The water balance of the Atankwidi Catchment shows that 23% of annual rainfall ends up as surface runoff in a wet year and 11% in a dry year (Martin 2006). The long-term average surface-runoff is 13% of rainfall and approximately 40% of surface runoff consists of interflow (shallow subsurface flow), with direct surface runoff as the main fraction. Base flow from groundwater negligible.

According to Martin (2006), groundwater contribution to streamflow is negligible, but this may be due to the fact that it was not observed at the catchment level such as in Atankwidi. The contribution of groundwater to streamflow may be observed at a larger scale such as at the sub-basin level. Because of the negligible contribution of groundwater to streamflow, the majority of the streams in the study area are perennial. This has made the development of small reservoirs and dugouts very key to the provision of continuous and sustainable surface water resources for various water uses in the catchment (de Fraiture and Giordano 2013). There are over 2000 small reservoirs developed in the Volta Sub-basin (ICOLD members-Burkina Faso 2001) with Anyari having about 48 active small reservoirs including dugouts (Ofosu 2011).

Dugouts are excavations positioned within the flood plains of rivers and streams (Ofori et al. 2006). Dugouts are usually positioned in depressions close to streams or rivers and may not necessarily have spillways nor are their banks constructed with boulders. Dugouts are constructed by scooping the sand in the flood plain/depression using bulldozers and excavators to create the embankments. The embankments of dugouts are not engineered or designed like the embankments of small reservoirs. Dugouts are constructed to receive surface water runoff through diversion channels from the streams during the rainy season and store the water for livestock farming, aquaculture, irrigation, and domestic water use during the dry season.

The main distinguishing feature between dugouts and small reservoirs is that while small reservoirs are constructed in the stream channel, dugouts are constructed in the flood plains of the stream and are fed by surface water in the flood plains. A second distinguishing feature is that dugouts have much smaller catchment areas ranging from 4 to 165 ha; have storage volumes ranging from 4000 to 58 000 m^3; full scale storage area of 0.04–3.2 ha; a maximum depth of 0.7–3.0 m; and embankment length of 38–320 m (Ofosu, 2011).

An assessment conducted in the Upper East Region of Ghana in 1995 by the Ghana Irrigation Development Authority (GIDA) showed that the impoundments of small reservoirs in general are fed with water from catchment areas ranging from 10 to 544 ha; have storage volumes ranging from 150,000 m^3 to 470,000 m^3, full scale storage area of 3.5–28 ha, a maximum depth of 2.0–6.5 m, embankment length of 100–1000 m and an earth/concrete channel spillway connected to one end of the embankment (Fig. 7).

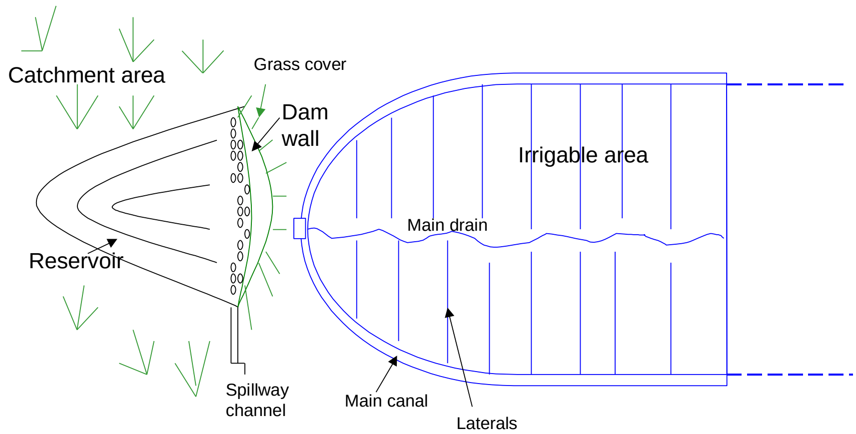


Figure 7. Schematic presentation of a small reservoir system (Source: Ofosu 2011).

Dry season irrigation

In semiarid regions such as the Anyari Catchment, dry season irrigation is key for poverty alleviation of the inhabitants. The indigenous people of the White Volta sub-basin, seeing the benefits of irrigation coupled with available government infrastructure in the form of small reservoirs and dugouts, have upscaled irrigation development using various endogenous technologies together with conventional approaches (Ofosu et al. 2010). Both groundwater and surface water sources are key to the successes of these irrigation schemes. Local farmers depend mostly on shallow groundwater, small reservoirs, and dugouts for their dry season irrigation. Farmers have various forms of water lifting mechanisms ranging from rope and bucket to gravity flow and diesel/petrol-powered pumps for their irrigation activities. The irrigated crops are mainly vegetables such as onions, pepper, and tomatoes in the small-scale irrigation systems, while rice is cultivated in the large-scale irrigation systems. The farm sizes of small-scale irrigation systems range from 0.01 ha to 1 ha and those of large-scale systems range from 0.5 ha to 5 ha (Ofosu 2011).

The irrigation potential of the White Volta sub-basin under the Water Resources Management study of the Volta Basin is estimated as 6% of the catchment area and amounts to 314,000 ha (Wiafe 1997). Data from groundwater studies conducted in the White Volta and prevailing irrigation activities can help to estimate the groundwater irrigation potential for the Anyari Catchment. The average annual groundwater recharge in the study area is about 66 mm/yr (Martin 2006).

The study therefore relied on the crop water use of tomato irrigation (900 mm/season) obtained by Ofosu et al. (2010) for shallow groundwater irrigation. Using a crop water requirement of about 900 mm/season (including transpiration and evaporation) the groundwater irrigation potential of the study area amounts to about 7% of the catchment. Studies conducted by Ofosu (2011) show that the sustainable groundwater irrigation potential in the Anyari Catchment is 7% if the irrigation efficiency is about 70%, consistent with rope and bucket irrigation. It should be noted that other competing groundwater uses can reduce this potential.

Based on estimates from Martin (2006), the total average annual runoff in the Anyari Catchment is about 69.75 × 109 m^3/yr (Martin 2006). If 10% of this runoff could be stored in small reservoirs, with the prevailing evaporation considered, the surface water irrigation potential can be further boosted by 7.82 km^2/yr. This amounts to about 1.45% of the catchment area. The irrigation potential is based on a crop water use of 640 mm by small reservoirs as obtained by Ofosu (2011).

Estimation of groundwater characteristics

From desk studies and site visits, two hand-dug wells and two boreholes were identified in Tekuru while two hand-dug wells and three boreholes were identified in Nyangua for the pumping test (Annex 2). At the time of going to conduct the pumping test, both boreholes in Tekuru had been fitted with hand pumps while the hand-dug wells had dried up. At Nyangua, one borehole had been fitted with a hand-pump. For this reason, the pumping and water quality tests were carried out on two boreholes and two hand-dug wells in Nyangua.

An official request was made to the community for the pumping test evaluation of two boreholes (herein labelled BH1 and BH2) and two hand-dug wells (herein labelled HDW1 and HDW2) within the Anyari Catchment in Kasena Nankana District of Ghana. The boreholes were drilled less than a year ago and were yet to be mechanized while the hand-dug wells were already in use. The request was, basically, to conduct pumping tests and water quality test on both the boreholes and hand-dug wells, and provide an interpretation of the results.

The two boreholes (BH1 and BH2) in Nyangua were about 500 m apart. BH1 was on the compound of Roman Catholic JHS while BH2 was located close to the palace of the community chief. The immediate surroundings of the two boreholes were dry vegetation and some gardening activities.

Similarly, each hand-dug well (HDW1 and HDW2) was located on vegetable farms in Nyangua and were about 100 m apart. Both wells were solely for vegetable farming. The vegetable farm on which HDW1 was located is for the Africa RISING project.

Shallow groundwater irrigation mapping

There are many shallow wells in the Anyari Catchment. Ofosu (2011) estimated the total area irrigated based on satellite images (Fig. 5). The private-led irrigation was predominately from shallow groundwater as during the dry season not much surface water is available in the area. The total irrigated area in the Anyari Catchment was estimated based on the analyses of 30% (1626 ha) of the catchment.

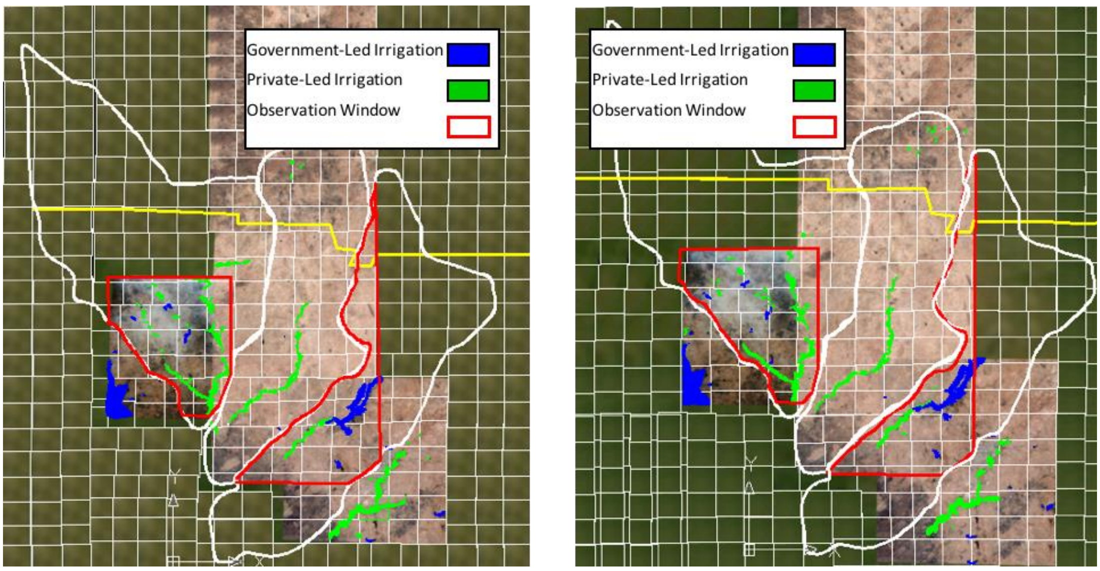


Figure 8. Irrigated areas observed in 2007 and 2010 (images taken on 10-01-2007 and 27-01-2010) (Ofosu 2011).

Table 1. Estimated irrigated area (in ha) from satellite images for the Anyari Catchment (Ofosu 2011).

Irrigation type	Government-led irrigation	Private-led irrigation
2003	60	380
2005	65	420
2007	44	485
2010	40	483

As observed from the image, the irrigated area mainly occurs in the vicinity of the river beds, where shallow groundwater is available. The study however did not identify the extent from the river banks to which the groundwater irrigation can be practiced thus establishing the potential irrigable area left for the catchment. This can be taken up in further studies. Beyond these shallow groundwater irrigable areas, the potential upscaling of groundwater irrigation will have to rely on deep groundwater which can be applicable in most parts of the Catchment.

Groundwater recharge estimation

The following steps were carried out to estimate the groundwater recharge for the boreholes and hand-dug wells:

(i) Conducting both step discharge and constant rate pumping tests on BH1 followed by recovery measurements. In all, BH1 was pumped for nine hours and allowed to recover in two hours.

(ii) Conducting both step discharge and constant rate pumping tests on BH2 followed by recovery measurements for each test. This borehole was first pumped in two steps and allowed to recover for an hour due to power problems. Afterwards a six-hour constant pumping was done and then allowed to recover for one hour again. Therefore, BH2 was pumped for 8 hours overall.

(iii) Conducting recovery tests on HDW1 and HDW2. These were done by rapidly pumping the water in both wells till they were nearly empty followed by recovery measurements for 3.5 h in HDW1 and 9 h for HDW2. The recovery for HDW1 was actually up to 24 h, but it was interrupted by the farmers after the 3.5 h mark.

(iv) Processing and analyzing the data generated in (i) to (iii) using the appropriate standard methods (MacDonald et al. 2005). The dynamic water levels for the pumping and recovery periods was plotted against time for the combined step and constant rate test and used to deduce the sustainable pumping and recovery rates of the boreholes.

Figure 6 shows the performance of the borehole at varying pumping rates and indicates that pumping up to 120 L/min would be possible for BH1. The recovery for BH1 after an hour was 97.8% and was not significantly different from the 98.2% achieved after two hours; indicating that the borehole had an excellent recovery rate. Borehole data obtained from the Community Water and Sanitation Agency (CWSA) show that borehole yields could go up to 360 L/min within the Ghana portion of the Anyari Catchment (Fig. 10).

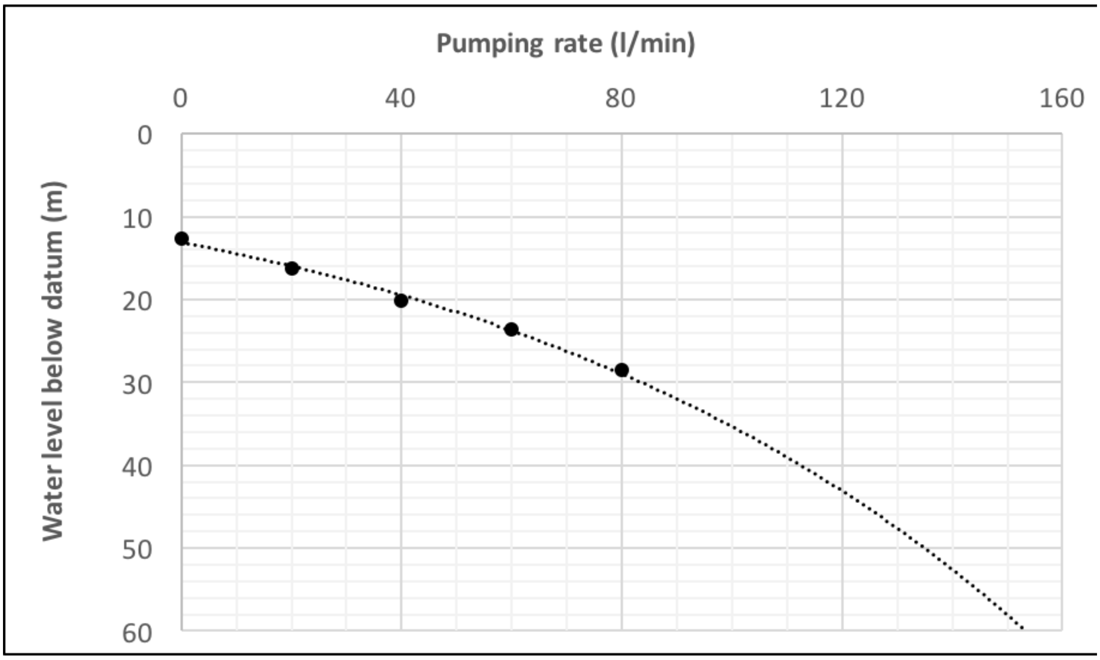


Figure 9. Drawdown curve for Nyangua BH1.

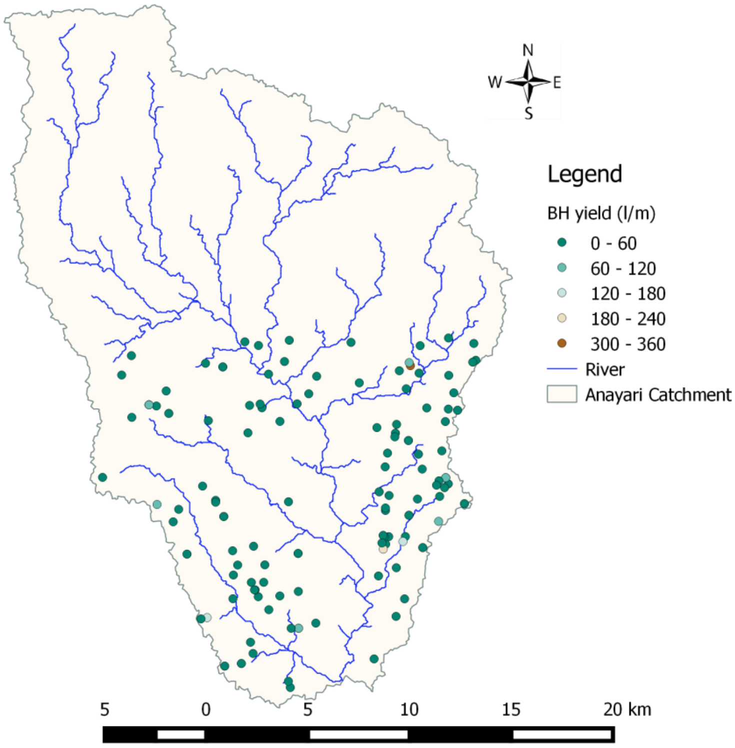


Figure 10. Borehole distribution and yields in the Ghana portion of the Anyari Catchment (Source: CWSA, Upper East Region).

The results show that:

(i) The Nyangua BH1, with an estimated depth of 52 m, can yield a maximum of 120 L/min and has a 98% recovery rate. Therefore, it can be mechanized for water supply. The recommended sustainable pumping rate for mechanization of the borehole should be 100 L/min to cater for possible usage throughout the day without stoppages.

(ii) The Nyangua BH2, with an estimated depth of 56 m, can sustainably yield 30 L/min and has an excellent recovery rate. This borehole had some construction defects, and that accounted for the low yield.

(iii) The Nyangua HDW1 is 0.6 m in diameter, has a depth of 9.23 m, an estimated yield of 1.03 L/min, and can fully recover in eight hours. Similarly, the Nyangua HDW2 has a diameter of 0.61 m, a depth of 10.15 m, an estimated yield of 0.60 L/min, and can fully recover in seven hours after withdrawals. Both wells are low-yielding and cannot sustain hand pumps.

Groundwater quality

The water quality of the two boreholes was conducted to examine their suitability for irrigation water uses. The parameters tested include electrical conductivity, color, TDS, odor, turbidity, temperature, pH, alkalinity, hardness, chlorides, nitrites, calcium, magnesium, sodium, iron, magnesium, phosphate, fluoride, and sulphate. The results indicate that both boreholes meet the standards for irrigation water quality for the parameters tested. The only outlier was the sodium content of BH2, although not highly significant (Table 2). The results indicate that both boreholes are suitable for drinking and irrigation water use.

Table 2. Water quality test results on the two boreholes.

<table>
<tr><th rowspan="2">Potential irrigation problem</th><th rowspan="2">Units</th><th rowspan="2">Nyangua BH1</th><th rowspan="2">Nyangua BH2</th><th colspan="3">Degree of minimum use</th></tr>
<tr><td>None</td><td>Slight to moderate</td><td>Severe</td></tr>
<tr><td>Salinity</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Electrical conductivity</td><td>$dScm^{-1}$</td><td>0.251</td><td>0.414</td><td>< 7.0</td><td>7.3–30.0</td><td>>30.0</td></tr>
<tr><td>TDS</td><td>Meg/L</td><td>171</td><td>310</td><td>< 450</td><td>450–2000</td><td>>2000</td></tr>
<tr><td>Specific ion toxicity</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Sodium (Na)</td><td>ASAR</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Surface irrigation</td><td></td><td>0.38</td><td>0.64</td><td>< 3.0</td><td>3.0–9.0</td><td rowspan="2">9.0</td></tr>
<tr><td>Sprinkler irrigation</td><td></td><td>-</td><td>-</td><td>< 3.0</td><td></td></tr>
<tr><td>Chloride (Cl)</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Surface irrigation</td><td>Meq/L</td><td>0.007</td><td>0.156</td><td>< 4.0</td><td>4.0–10.0</td><td rowspan="2">>10</td></tr>
<tr><td>Sprinkler irrigation</td><td>Meq/L^{-1}</td><td></td><td></td><td>< 3.0</td><td></td></tr>
<tr><td>Boron (B)</td><td>Mg/L</td><td>-</td><td>-</td><td>< 0.7</td><td>0.7–3.0</td><td>>3.0</td></tr>
<tr><td>Miscellaneous effects</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Nitrogen</td><td>Mg/L</td><td>< 0.01</td><td>< 0.01</td><td>< 5.0</td><td>5.0–30</td><td>>30.0</td></tr>
<tr><td>Bicarbonate</td><td>Meq/L</td><td>1.179</td><td>1.767</td><td>< 1.5</td><td>1.5–8.5</td><td>>8.5</td></tr>
<tr><td>pH (Normal = 6.4–8.4)</td><td></td><td>7.28</td><td>7.48</td><td></td><td></td><td></td></tr>
</table>

Groundwater availability

From the mapping, pumping test, and water quality test, it is clear that the communities are using groundwater for dry season irrigation; the majority of the farmers use shallow groundwater of less than 10 m depth (7500 shallow wells were mapped) due to its relatively low cost. Pumping tests show that yields from these shallow wells are low. The areas favorable for shallow groundwater irrigation are located near the stream therefore the potential irrigable area with shallow groundwater is limited. Water can be abstracted by human labor. Water from shallow wells is used for various purposes although the main use is farming. With an average area per farm or well, total irrigation from shallow wells in the area is estimated to be 966 ha. Shallow wells normally dry up by the end of the dry season.

The Anyari Catchment has a number of deep wells (143 in the Ghana section), mainly installed for domestic water supply by local NGOs. Well depths range from 50 to 90 m. Six wells were recently installed by the Africa RISING project for dry season farming. These wells have higher yields than shallow wells, but require substantial investments and operational costs. Potential irrigated area is close to 1 ha per borehole with a yield of 75 L/min (Mante et al. 2017). Total irrigated area from deep wells is less than 10 ha.

The estimated total area irrigated by groundwater in the Anyari Catchment is 9.76 km^2. This amounts to an annual abstraction of 8.78 km^3/yr With a potential annual recharge of 32.52 km^3/yr the current groundwater abstraction is 27% of the potential. However, the potential groundwater irrigation cannot be totally irrigated by shallow wells as they are restricted to areas around the streams where groundwater level is high.

Shallow groundwater is the preferred groundwater irrigation source for smallholder farmers considering that they are resource poor and will not be able to afford high investment costs associated with deep wells. Shallow groundwater is found near the rivers, and extension of shallow groundwater irrigation will have to take place in those areas. Further study is needed to determine the extent to which shallow groundwater can be up scaled in the catchment.

Surface water estimation

Small reservoirs and dugouts

The Anyari Catchment has close to 50 functional small reservoirs and dugouts in both Ghana and Burkina Faso (with surface areas between 1 and 100 ha). The Ghana section alone has about 24 small reservoirs and dugouts (Fig. 11). The small reservoirs and dugouts that are close (within ≈5 km) to the two communities (Tekuru and Nyangua) and reliable (available all year) were 13 (Fig. 9) with a total storage of about 1 million m^3 (see Annex 3 for inventory of reservoirs and dugouts). The volume of the reservoirs range from 15 000 m^3 to 180 000 m^3.

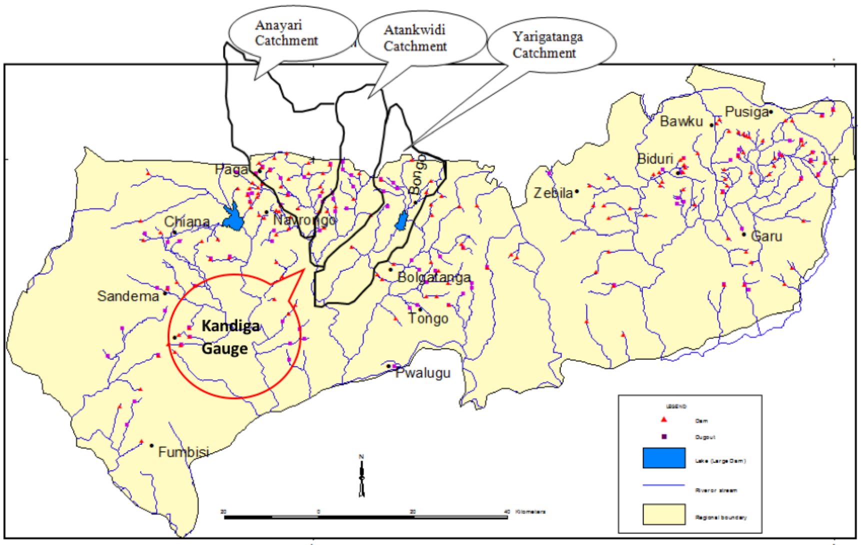


Figure 11. Location of small reservoirs and dugouts in the Anayari Catchment (Source: adapted from GLOWA Volta Project).

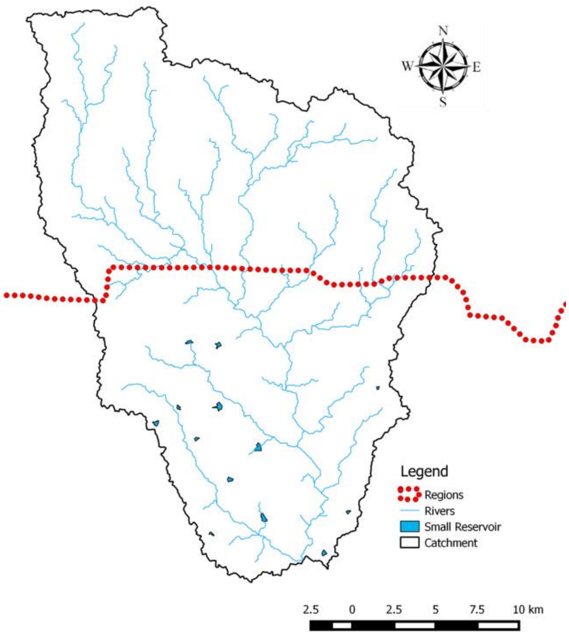


Figure 12. Locations of small reservoirs easily accessible to Tekuru and Nyangua communities.

Streamflow analyses

The gauging station for the Catchment is located at Kandiga along the Bolgatanga-Navrongo Road, which is at the downstream end and therefore almost captures the total runoff from the 542 km^2 area (Fig. 11). There is no river gauge station within the catchment. The useful streamflow data was only for two years (2004–2006), and this was used for analyses.

It was observed that the streamflow data did not show any dryness in the dry season, however upon interrogation of the hydrological services, it was explained that they deliberately calibrated the gauge to take care of interflow within the river bed. This is not accurate as it was observed that the riverbed dries up during the dry season.

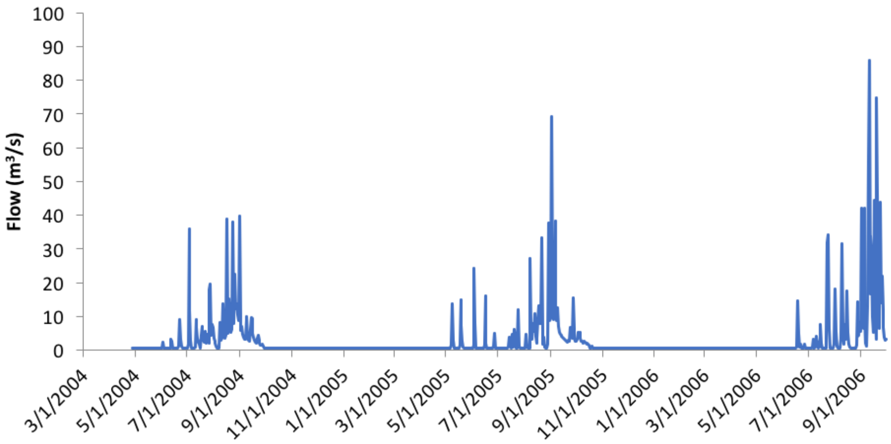


Figure 13. Streamflow from Kandiga Gauge station (Source: GLOWA Volta Project).

Figure 13 gives a 90-day minimum streamflow of 0.6 m^3/s. This means there is about 19 million m^3/yr flowing downstream that could be used barring environmental flow requirements into the White Volta River. The average monthly runoff generated in the Ghana portion of the Anyari Catchment is about 9.4 million $m^3/month$ with the highest runoff of 42.5 million m^3 generated in August (≈16 m^3/s) and the lowest of 0.07 million m^3 generated in January (0.03 m^3/s) within the catchment (Fig. 14). The extreme low flow days last for a maximum of seven days (Fig. 15.

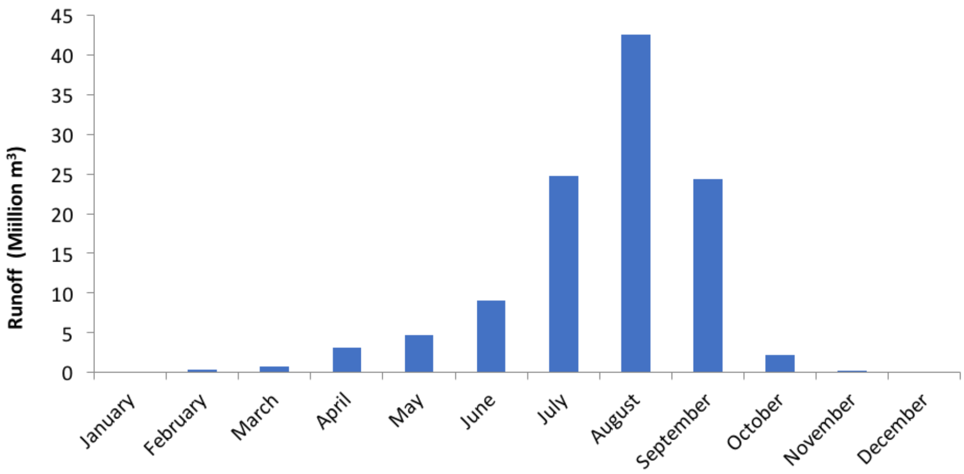


Figure 14. Monthly average runoff from precipitation in the study area. (Source: meteorological services.)

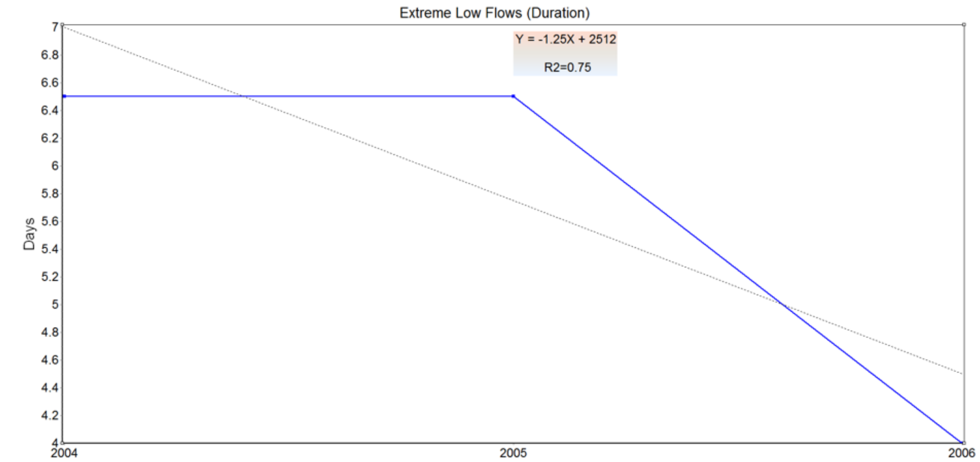


Figure 15. Extreme low flow duration.

An annual flow-duration curve (Fig. 16) and monthly flow duration curves were plotted for the very dry months (February and March) and wet months to assess the reliability of streamflow for irrigation purposes. The flow duration curve (Fig. 16) showed that flows above 10 m^3/s can be guaranteed only 5% of the time which underscores the importance of storing water in the wet season for dry season use. Currently, there is very limited surface water supply during the dry season which can be used for irrigation. This shows the importance of storage in the catchment from small reservoirs to shallow groundwater to supply sufficient water for dry season irrigation.

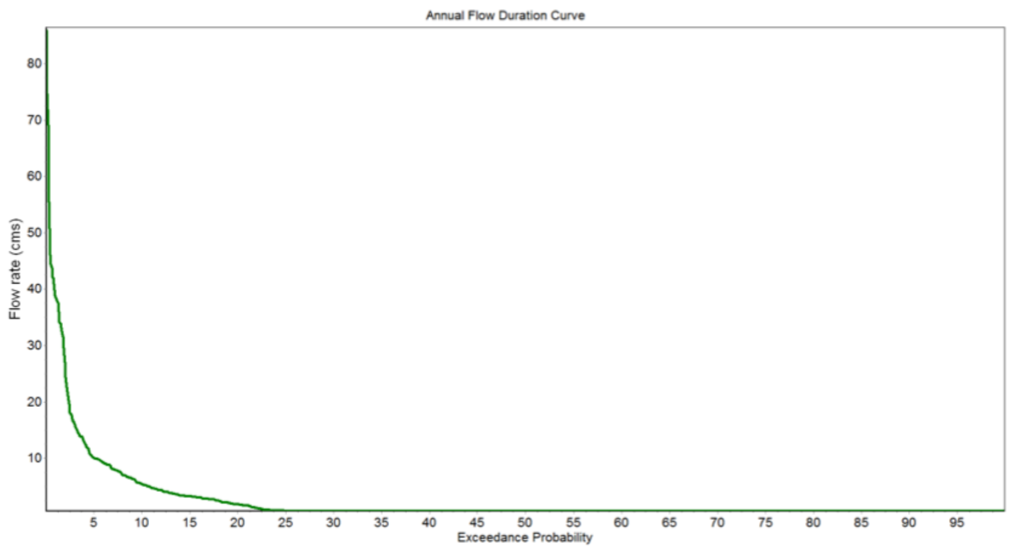


Figure 16. Annual (2004–2006) flow duration curve for Kandiga streamflow.

Groundwater–streamflow partitioning

The contribution of groundwater to streamflow is low but significant as shown in the base flow index given in Figure 17. The base flow index is the ratio of long-term mean base flow to total streamflow and shows the contribution of groundwater to streamflow. This value was between 0.2 and 0.28, which is significant due to subsurface flows as stated in Section 2.2 of this report. This value however reduced with time which points to the fact that it could become insignificant. This aspect requires more studies.

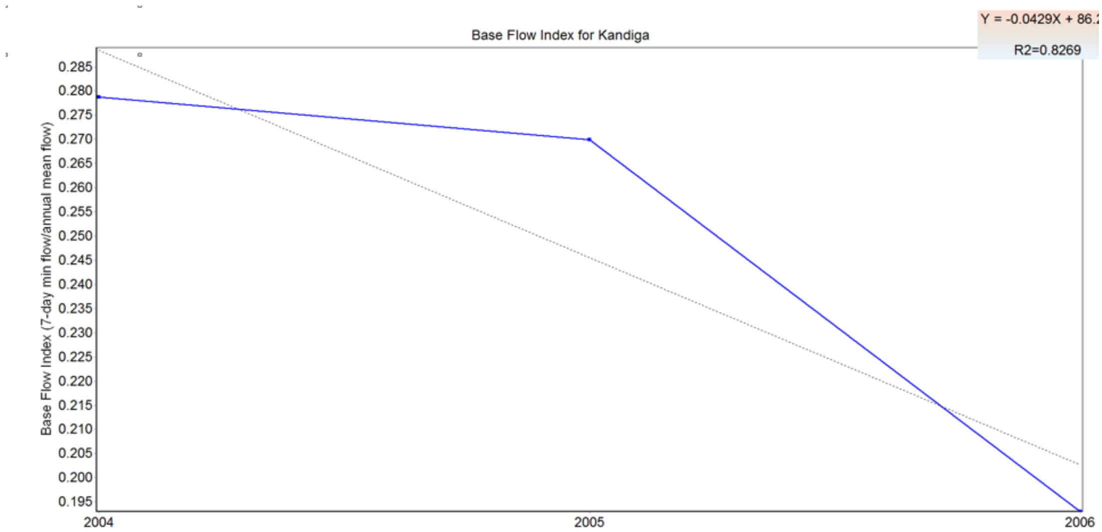


Figure 17. Base flow index for the catchment using flow data from Kandiga.

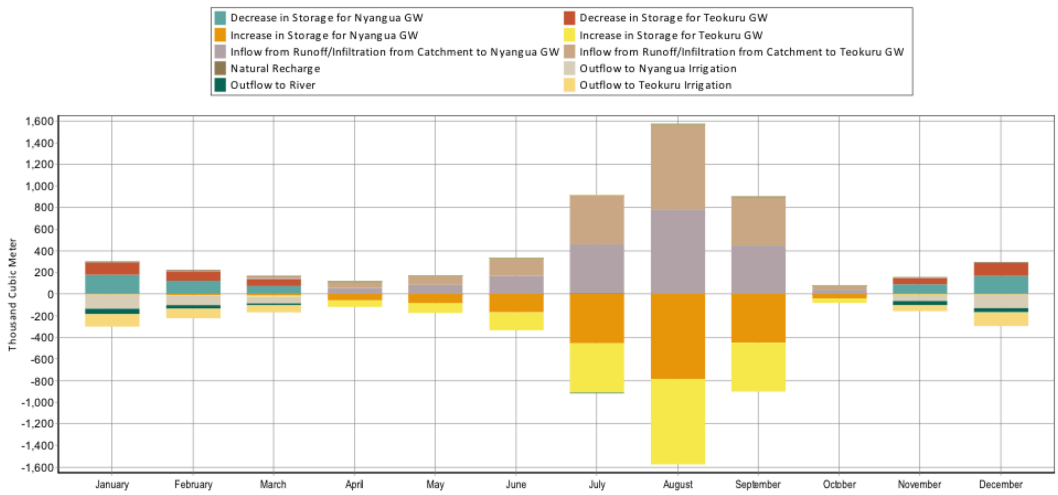


Figure 18. Groundwater inflows and outflows in the catchment.

Figure 18 shows that groundwater contributes significantly to streamflow especially during the dry season as already shown with the base flow index for the catchment using the streamflow analyses.

Estimation of irrigation potential (groundwater and surface water)

The irrigation potential of the catchment area was estimated using the WEAP modelling tool. WEAP operates on the basic principle of a water balance and is applicable to municipal and agricultural systems, single catchments, or complex transboundary river systems. The WEAP model was setup to best fit the water resources and water-use of the study area. The study models the irrigation development and other water uses within the catchment.

Because of limitations of the study period, the majority of the required data needed for estimating the irrigation potential could not be obtained on site during the study period. As a result, data from Ofosu (2011) conducted within the catchment area on various irrigation technologies was used in estimating the irrigation potential for the catchment area. This data included crop water demand, irrigation efficiencies, rainfall-runoff coefficients, water-use pattern, competing water uses, and yield.

Groundwater irrigation potential

The annual groundwater storage potential in the Ghana portion of the Anyari Catchment is about 110 million m^3/yr. However, to ensure sustainable development and use of the groundwater resources, the recharge rates must be considered. The annual recharge and monthly distribution is given in Figure 19. The average annual groundwater recharge in the Ghana portion of the catchment is 4.12 million m^3 with a monthly average of 0.34 million m^3. This implies that considering a maximum water requirement of 900 mm/season as given in Section 2.3 of the report, an area of about 4500 ha in the Ghana portion can be put under sustainable groundwater dry season farming without any water stress. From Ofosu (2011), there is an average of about 48 shallow wells per hectare, implying that for 4500 ha, an average of 216 000 shallow wells will be developed. Tomatoes, for example, require water of between 400 and 600 mm/season which means the area could be increased based on the types of crops selected and the irrigation efficiency. The observed water use of 900 mm/season is quite high and not sustainable on the long-term and for the upscaling of groundwater irrigation. Sustainable agriculture intensification using groundwater resources requires some level of mechanization to enhance production.

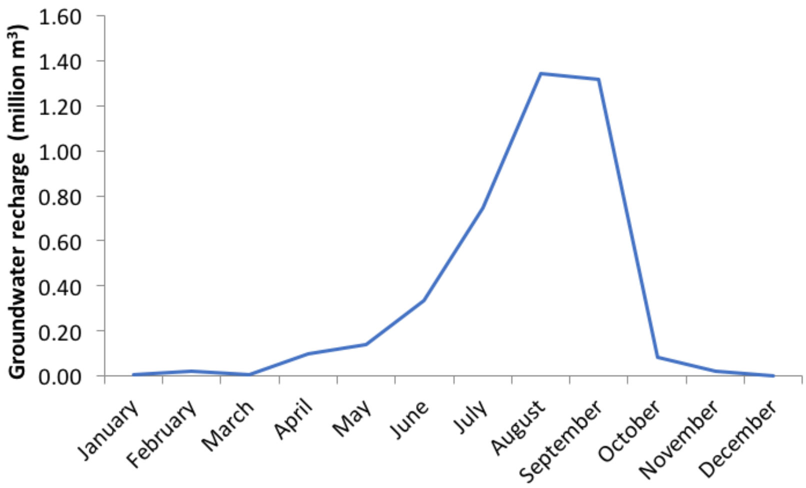


Figure 19. Average monthly groundwater recharge in the Anyari Catchment.

Surface water irrigation potential

Although the average annual runoff is 112 × 10^6 m^3/yr, most communities are further away from streams, hence may require the harvesting of surface runoff in small reservoirs and dugouts close to them to make use of the water available. The reliable reservoirs in the Ghana portion of the basin stores about 1 × 10^6 m^3/yr of water which is available all season. This can irrigate about 156 ha of farmland using a 640 mm/season water requirement which is the average water consumption for small reservoirs (Ofosu 2011). Harvesting just 10% of the runoff using dams, dugouts, and underground tanks can lead to an expansion of the irrigable area to 1750 ha, which could be used for dry season agriculture. It must be noted that the streams dry up in the dry season, hence having an efficient storage system seems to be the most logical way to intensify agriculture.

Conclusions and recommendations

Conclusions

Based on the document reviewed and the analysis done in the previous chapters, the following conclusions have been drawn for the study:

- The study has shown that the resilience of farmers to climate change could be increased through groundwater and surface water dry season vegetable irrigation.
- The sustainable use of groundwater depends largely on the recharge rates which is a maximum of about 6% of annual rainfall.
- Most communities in the catchment are quite a distance (> 5 km) away from streams and rivers, hence this makes river irrigation unattractive as compared to harvesting runoff on site and using it for dry season vegetable farming.
- Both groundwater and surface water irrigation in the Ghana section could be upscaled from 500 ha and 50 ha to 4500 ha and 1750 ha, respectively. Current groundwater irrigation is 11% of the potential and surface water irrigation a mere 3% of the potential.
- Upscaling irrigation in the catchment to 6250 ha could lead to about 0.01% reduction in streamflow to Akosombo. This is not significant with regards to annual contribution but could have dire consequences in the dry season months.

Recommendations

The following recommendations are made from the study:

- Wetlands which are major areas for groundwater recharge should be preserved to ensure groundwater sustainability.
- There is ample room for expanding irrigation in the Anyari Catchment considering the water resource availability, however, there are financial and socioeconomic constraints in the development of irrigation, which should be identified so that the government can develop policies and plans to address these issues.
- Improving irrigation efficiencies will allow for larger areas to be irrigated during the dry season.
- Further studies are needed to improve the characterization of the catchment. The study period was too short to carry out a more detailed study.

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Annexes

Annex 1. Summary of boreholes and wells surveyed in the study area

Community	Type of GW	Features around	Electricity	Location & Elevation	Depth	Comment
Tekuru	HDW		No	N: 10° 54’ 49” W: 1° 2’ 18” E: 198 m	11 m	• Well dries up in dry season • Well depth limited by granitic bedrocks • Well located in 1 ha vegetable farm • Water used for irrigation only
Tekuru	BH1		No	N: 10° 54’ 55” W: 1° 2’ 45” E: 220.9 m		• Cereal gardens around the borehole • Multipurpose use of water (everything) • Water available throughout the year • Water flows out after 2 pumps (as at 1:10 pm) • Over 40 years in use • About 60 houses with an average size of 12/house depend on the borehole
Tekuru	BH2	School	Yes (10 m away)	N: 10° 54’ 47” W: 1° 2’ 49” E: 218.4 m		• Drilled and constructed on 15 June 2015 • Uncompleted • Sandy loam topsoil
Nyangua	BH1	School	Yes (10 m away)	N: 10° 56’ 24” W: 1° 4’ 19” E: 222.9 m		• Compact sandy topsoil • Dugout 10 m from BH • Water flows after 2 pumps (1:40 pm)

						• Multiple uses and water is available throughout the year
Nyangua	BH2	School	Yes (7 m away)	N: 10° 56’ 18” W: 1° 4’ 30” E: 221.2 m		• Uncompleted • Millet farms around • Constructed in March, 2016
Nyangua	BH3	Solar street light	No	N: 10° 56’ 6” W: 1° 4’ 0” E: 221.6 m		• Damaged hand pump • Millet gardens around BH
Nyangua	HDW		Yes (30 m away)	N: 10° 56’ 1” W: 1° 3’ 55”		• Granitic drill cuttings. • Dries out in dry season • 5 m static water level

Following are pictures of the wells.

Plate 1 Tekuru hand-dug well.

Plate 2. Tekuru borehole (BH1).


Plate 3. Tekuru borehole (BH2).


Plate 4. Nyangua borehole (BH1).


Plate 5. Nyangua borehole (BH2).


Plate 6. Nyangua borehole (BH3).


Plate 7. Nyangua hand-dug well.

Annex 2. Inventory of reservoirs and dugouts within the Anyari Catchment (Source: IDA Bolgatanga)

INVENTORY OF DAMS (Dm)/ DUGOUTS(Dg) IN THE ANYARI CATCHMENT OF GHANA						
Name/Type/Location Number	**Nearest town**	**Year of construction**	**Max depth (m) (Approximate)**	**Catchment area (ha)**	**Estimated FSL reservoir area (A) (ha)**	**Estimated storage (V) (ha-m)**
PINDAA (Dg) (33)	PINDAA	1952	3.60	60	3.1	5.6
ZENGA (Dm) (34)	PAGA	1958	4.00	75	6.2	11.8
PAGA NANIA (Dm) (30)	PAGA	1960	5.50	272	4.65	8.7
NAKOLO (Dm) (53)	PAGA	1960	3.60	50	5.3	10
ANAMA MANYORO (Dm) (54)	NATUGNIA	1960	1.60	65	3.2	5.8
GUMONGU (Dm) (56)	NANYORO	1964	1.20	25	2.2	3.8
BADUNU (Dg) I (57)	PAGA	1960	2.00	30	2.6	4.6
ATABULA (Dm) (58)	PAGA	1958	4.00	65	5.95	11.3
BAGANIA GIA (Dm) (46)	GIA	1962	3.00	55	4.8	9
BIU (Dm) (70)	BIU	1960	5.00	75	15	29.4
NADEO (Dg) (78)	NAGA	1946	1.50	35	1.7	2.8
NYABISI (Dg) (79)	NAGA	1992	0.40	30		
NABAGO (Dg) (81)	SIRIGO	1953	3.00	45	3.5	6.4
BUMVISI (Dg) (92)	KANDIGA	1964	3.00	55	2	3.4
ATIBABISI (Dg) II (95)	KANDIGA	1945	2.00	50	0.7	0.8
ATIBABISI (Dm) I (96)	KANDIGA	1963	5.00	95	12	23.4
KURUGU (Dm) (94)	KANDIGA	1940	3.00	75	3	5.4
AZAASI (Dm0 (97)	KANDIGA	1960	6.00	80	4	7.4
MIRIGU (Dg) I (98)	KANDIGA	1950	3.00	35	9	17.4
GONNO (Dg) (89)	MIRIGU	1989	1.50	30	0.5	0.4
KUMBUSGU (Dg) (90)	MIRIGU	1986	2.50	45	0.6	0.6
CONSAAR (Dg) (93)	MIRIGU	1976	2.00	50	0.8	1

KABAA-BOKA (Dg) (87)	SIRIGU	1989	2.00	60	0.8	1
NYONGU (Dg) (82)	SIRIGU	1987	2.20	45	1.8	3
AFORBGA (Dm) (84)	SIRIGU	1989	2.50	225	16	31.4
NAVIO (Dm) (55)	PAGA	1958	6.00	115	10	19.4

* Dg –dugout; Dm –small reservoir.