IWMI
WORKING PAPER 142

Typology of Irrigation Systems in Ghana

Regassa E. Namara, Leah Horowitz, Shashidhara Kolavalli, Gordana Kranjac-Berisavljevic, Busia Nambu Dawuni, Boubacar Barry and Mark Giordano

International Water Management Institute

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Namara, R. E.; Horowitz, L.; Kolavalli, S.; Kranjac-Berisavljevic, G.; Dawuni, B. N.; Barry, B.; Giordano, M. 2010. *Typology of irrigation systems in Ghana*. Colombo, Sri Lanka: International Water Management Institute. 35p. (IWMI Working Paper 142). doi: 10.5337/2011.200

/ typology / surface irrigation / communal irrigation systems / farmers / water users / associations / smallholders / irrigation management / public sector / private sector / wastewater irrigation / groundwater irrigation / tube well irrigation / wells / case studies / Ghana /

ISSN 2012-5763
ISBN 978-92-9090-739-8

Please direct inquiries and comments to: *IWMI-Publications@cgiar.org*

A free copy of this publication can be downloaded at
www.iwmi.org/Publications/Working_Papers/index.aspx

Acknowledgements

This publication is dedicated to the late Leah Horowitz, who left the comfort of her country (USA) with the noble objective of contributing to poverty reduction in Africa, but could not live up to it because of her sudden death due to a tragic car accident. She will always be remembered by all of us associated with this publication.

The authors would like to thank the participants of the brainstorming workshop, which took place on December 12, 2008, at IWMI's Ghana office premises. The participants included Mr. Samuel Manu Ansah (Regional Director for Upper East region, GIDA), Mr. Vitus Ayingayure (Regional Director for the Northern Region, Ghana), Mr. James Akatse (Deputy Director, Agronomy, GIDA), Mr. Chris Feruta (Deputy Director, Agronomy, GIDA), Dr. Wilson Agyare (Lecturer, KNUST) and Hon. Edward Kofi Ahiabor (Former District Chief Executive, Keta District). The ideas and views, which transpired during the workshop, have contributed significantly to the preparation of this paper.

Project

This study was initiated as part of the project titled 'Appraising Ghana's Public and Private Irrigation Systems: Analyzing Performance, Productivity, Constraints and Opportunities'.

Collaborators

The following organizations collaborated in the research conducted for this paper.

International Water Management Institute (IWMI)

Ghana Irrigation Development Authority (GIDA), Ghana

International Food Policy Research Institute (IFPRI), USA

Donors

The project was supported by Ghana Strategy Support Program of the International Food Policy Research Institute (IFPRI).

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Summary

Ghana aspires to attain a middle income status by the year 2015. The accelerated growth of the agricultural sector is crucial for attaining this goal, even though the development of the oil sector may provide additional impetus for boosting the overall economic transformation. Modernizing agriculture by improving the performance of the existing irrigation sector, utilizing the country's significant irrigation potential, mechanization, improving farmers' access to improved technologies such as high-yielding varieties, improved agronomic practices, and crop protection techniques can ensure an accelerated growth in the agricultural sector.

At present, Ghana is endowed with adequate water resources given the country's demographic situation. The total water withdrawal as a percentage of total renewable water resources is 1.8% and an estimated 66.4% of this minuscule withdrawal is used for irrigation. The magnitude and structure of the irrigation sector in Ghana is not well understood nor is the irrigation potential of the country. Estimates of Ghana's irrigation potentials including valley bottoms and floodplains range between 0.36 and 2.9 million hectares (Mha). Thus, understanding the structure of Ghana's current irrigation sector through systematic classification would pave the way for identifying the right mix of interventions for improving performance and productivity in this sector, and for improving the planning of future irrigation development initiatives.

Ghana's irrigation sector is often equated to public or communal surface irrigation schemes, particularly in the 22 irrigation schemes managed by the Ghana Irrigation Development Authority (GIDA)/Irrigation Company of Upper East Region (ICOUR). The current study has revealed that irrigation in Ghana is already significantly larger as compared to official statistics. Determining the exact area of irrigated agriculture in Ghana is beyond the scope of this study and is undoubtedly a priority follow-up activity. Diverse typologies of irrigation systems were noted, which can be categorized into two broad classes namely, conventional and emerging systems. The conventional systems are mainly initiated and developed by the Government of Ghana and nongovernmental organizations (NGOs), or are developed by communities or individuals over a number of years. The specific typologies under conventional systems are: public surface irrigation systems, small reservoirs, wastewater irrigation, recession agriculture or residual moisture irrigation, and shallow groundwater irrigation in the coastal areas of southeastern Ghana, based on traditional lifting technologies.

The emerging systems are those irrigation systems initiated and developed by private entrepreneurs and farmers, either autonomously or with little support from the government and/or NGOs. The emerging systems include: groundwater irrigation systems based on contemporaneous lifting or pumping technologies, river or stream lifting or pumping-based irrigation systems, public/private partnership-based systems, out-grower systems, lowland/inland valley rice water capture systems, and private small-reservoirs systems. It is difficult to establish the extent of area of the emerging systems. But, it is believed that the area is manyfolds more than that of the conventional/public irrigation systems. For instance, two 3.5 HP pumps, communally owned by 100 farmers irrigated about 20.1 hectares (ha) in Ashanti. The corresponding value for two small reservoirs, Tanga and Weega, in the Upper East Region is 7.7 ha serving about 314 farmers.

The emerging systems are based on access to mobile and flexible pumps. Pumping is based on diverse sources of energy such as diesel, petrol, wind, electricity and possibly solar energy. The water sources are also numerous including groundwater and various surface water sources. The unique attributes of the emerging systems are that they allow farmers to access water on demand and to make autonomous production decisions. The cropping patterns differ between

the emerging and conventional irrigation systems. Whereas high-value crops such as fruits, vegetables and trees are grown under emerging irrigation systems; mainly rice is cultivated under conventional irrigation systems.

Despite their significance and recognition in Ghana's irrigation policy, the emerging irrigation systems get inadequate public support because:

- There is no centralized effort to monitor and regulate the development of the emerging irrigation systems; and
- The extension service is inadequate. In the absence of support from public extension systems, farmers are experimenting to find out appropriate agronomic practices, on-farm water management or irrigation techniques, and crop protection practices unaided.

Thus, it is recommended that an apex body be established with a mandate to monitor, regulate, manage and facilitate the development of the emerging irrigation systems in Ghana. This apex body may be a part of GIDA, but should also be entrusted with the added responsibility of providing research and extension support to the dynamic irrigation systems of Ghana.

INTRODUCTION

In Ghana, agriculture accounts for about 37.4% of the gross domestic product (GDP) and employs 56% of the total economically active population. It is predominantly practiced in smallholder, family-operated farms, which produce about 80% of Ghana's total agricultural output. About 2.74 million households operate a farm or keep livestock and 90% of farm holdings are less than 2 ha in size. Women are the predominant producers of the annual crops. In addition, this sector contributes an average of 12% and 8% to tax revenue and total revenue, respectively. Therefore, Ghana cannot achieve economic growth and poverty reduction without a significant improvement in the agricultural sector.

Only about 38.9% of the total agricultural land area is currently cultivated. Production levels of the major staple food crops in a normal rainfall year are adequate, particularly for non-grain crops. However, seasonal food insecurity is widespread, mainly due to excessive dependence on rain-fed agriculture. Generally, productivity is low and variable because of the prevailing traditional low external input, shifting cultivation farming systems and reliance on rain-fed agriculture. With the population growth rate estimated at 1.7% and the growing demand for industrial crops for local industries and for export, irrigated agriculture is an important factor in promoting agricultural growth. Ghana's overall national goal is to attain a middle income status with a per capita income of US$1,000 by the year 2015. Achievement of this national goal requires the agricultural sector to lead the process through accelerated growth. Modernizing agriculture through mechanization, irrigation and use of improved technologies can contribute to the achievement of this objective.

Ghana is endowed with adequate water resources, particularly given the country's current demographic situation. The country receives an average annual precipitation of 283.2 billion cubic meters (BCM). The total actual renewable water resources is 53.2 BCM per year, 43% of which originates outside of Ghana's international borders, which means that 30.3 cubic kilometers (km^3) per year are internally produced. About 22.9 km^3 of surface water enters the country annually, of which 8.7 km^3 comes from Burkina Faso, 6.2 km^3 from Côte d'Ivoire and 8 km^3 from Togo. Even though the availability of water resources in Ghana can be judged as adequate when compared to the situation of many water-scarce countries, it is below that of water-rich countries. The per capita renewable water resources availability is about 2,489 cubic meters (m^3) per year in Ghana, while the corresponding values for sub-Saharan Africa, Europe and North America are 6,322.5 m^3, 10,655.1 m^3 and 19,992.5 m^3, respectively. The total dam capacity of Ghana is estimated at 148.5 million cubic meters (MCM).

The total withdrawal as a percentage of total renewable water resources is 1.8%. The main consumptive water uses in Ghana are for domestic, industrial and irrigation purposes. In 2000, about 235 MCM was withdrawn for domestic purposes, 95 MCM for industry and 652 MCM for irrigation, resulting in a total water withdrawal of 982 MCM. The current water use for hydroelectricity generation (only at the Akosombo Dam), which is non-consumptive water use, is 37.843 km^3 per year (FAO 2009). The per capita water withdrawal is 50 m^3 per year, which is low when compared to the sub-Saharan Africa average (173 m^3 per capita per year). For comparison purposes the corresponding value for North America is 1,663 m^3 per capita per year.

Historical accounts trace irrigated agriculture in Ghana to a little over a century ago (Smith 1969), but the practice dates back to as early as 1880 in the Keta area on land above flood level between the lagoon and the sandbar separating it from the sea. Irrigation broadly defined may include sophisticated and automated drip irrigation, sprinkler irrigation, application of water by a watering can or a watering hose, etc., which make it possible for the irrigation of lands on steep slopes. Thus, the concept of irrigation potential for Ghana may be broadly defined to include a much higher area than as stated in previous estimations. It was only in the late 1950s (soon after independence) that the irrigation sector obtained all-round public support. Historical records indicate that the Dawhenya and Asutsuare projects are among the first batch of irrigation projects that received public support in Ghana. Even though the records date irrigation in the country to about a century ago, it is clear that serious irrigation is a more recent phenomenon. According to Agodzo and Bobobee (1994), some forms of shallow tube well irrigation could also be identified in Southeastern Ghana in the 1930s. Estimates of Ghana's irrigation potential are wildly divergent, ranging from 0.36-1.9 Mha (Agodzo and Bobobee 1994). The potential of valley bottoms and floodplains could add another 1.0 Mha of land that could be cultivated mostly with rice by employing water management technologies such as bunding, leveling and puddling.

The Government of Ghana is currently appraising a large-scale commercial irrigation project known as the 'Accra Plains Irrigation Development Project' to develop the Accra Plains using water from the Volta River. This project, if realized, will have an area twenty times greater than the entire current public/state irrigated area in the country. The project will accommodate about 10,000 modernized irrigation farms (based on a minimum of 20 ha per farm) with a capacity to give employment to about 100,000 people. The project is expected to provide a gross production value of US$0.6 billion per annum. But, the cost to implement the whole project can reach about US$2.5 billion.

It is believed that, overall, about 27,900 ha of a total of 30,900 ha (or 90%) were equipped for irrigation, and were actually irrigated in 2000. This is due to the deterioration of infrastructure and lack of sufficient funds for maintenance since 2000. However, there are many ongoing or pipeline projects that aim to rehabilitate non-functioning and under-performing irrigation schemes. Power irrigated area as a percentage of the area equipped for irrigation is 57.6%. Crops grown under irrigation include rice and vegetables such as tomatoes, okra and exotic vegetables (cabbage and spring onions). Rice area under formal irrigation is about 40% of the total area, with vegetables making up the rest. Peri-urban irrigation is devoted to exotic vegetables. New small-scale irrigation projects that can irrigate a total of an additional 3,086 ha are currently either under implementation or under feasibility studies. The size of these irrigation schemes ranges between 2 to 210 ha. However, one issue which generates a lot of pessimism about irrigation in Ghana is the issue of cost (Kyei-Baffour and Ofori 2006). According to the World Bank (1985), the budgetary expenditures on irrigation are substantial compared to its limited role in overall agriculture.

This paper develops and presents a typology of irrigation systems in Ghana. It is intended to enhance knowledge of irrigation methods and management with the aim of improving system performance and productivity. The objective is to present a classification system, which is relatively simple but well-suited for the intended audience, and one that may also be a useful starting point for developing more detailed analyses. The paper also provides an introduction to irrigation in Ghana and an understanding of the relationship between system types and their physical as well as social features.

METHODOLOGY

The two common methods for categorizing irrigation schemes in Ghana have been by organizational structure and size. Structural classifications usually distinguish between formal and informal systems. Formal systems are those developed and sometimes managed by the government, often with donor funding. In Ghana most formal systems were developed between the late 1940s and 1970s. Informal systems are considered those developed and managed by communities or individuals. Informal schemes are often ignored in statistics and policy, but can account for the majority of irrigation in many countries, like in Ghana (IWMI 2007). Size classifications usually divide systems into small (up to 200 ha), medium (200-1,000 ha) and large (more than 1,000 ha). Ghana's new irrigation policy (2010) combined both approaches to some extent and officially classifies systems as informal, formal and large-scale commercial.

This latest classification is clearly valuable and provides recognition of newly emerging private sector forces. Here we develop an even more detailed typology which fits within the typology officially formed by the irrigation policy. The additional nuance highlights sources of water as well as the various ways in which it is distributed and by whom. This allows more understanding of needs within specific areas of the irrigation sector and can sharpen investment discussion and planning.

To develop the typology, we started from the official policy and categorize systems into formal, informal and large-scale commercial. We then consider the sources of water used to supply irrigation water (rivers, reservoirs, lakes, groundwater, domestic wastewater and storm water, and water capture). For formal systems, rivers, reservoirs and lakes are further typified by how water is acquired from the source (by gravity or pumps) and how it is delivered to fields (gravity or sprinklers). A separate category for government driven but community managed reservoirs is maintained.

For smallholder river systems, a simple distinction is added between private and communal ownership/management. Groundwater systems are characterized into one of five categories based on technology and usage. Water capture systems are divided into two fundamental forms, recession agriculture and inland valley systems.

Finally, large-scale commercial systems are categorized as purely private or public-private partnerships.

Table 1 shows the detailed breakdown as applied to the typology in the official irrigation policy. Only those categories found within Ghana are shown for each division. The purpose of the typology is both to focus attention on the differentiations and to stimulate further refinement.

As irrigation investment is high on the agenda of both the government and donors, there is increasing discussion of a differentiation between "conventional systems" and "emerging systems". Conventional systems are those which have been in existence for a substantial time and for which investment interest and/or potential appears low. Emerging systems are relatively new approaches to irrigation in Ghana or are less well recognized and are attracting new interest in understanding and/or investment. Each system is also categorized in Table 1 as either conventional or emerging. As a key purpose of this paper is to further catalyze thinking on investment priorities, the detailed discussion of each irrigation system is also organized around the conventional/emerging breakdown.

Data Sources

Information on irrigation systems in Ghana was gathered through: (1) conducting a one-day brainstorming workshop involving professionals from GIDA, IWMI, IFPRI, University for Development Study (UDS), and Kwame Nkrumah University of Science and Technology (KNUST); (2) collation of information, reports and data from GIDA and IWMI as well as other sources, including online publications and published reports on work in Ghana; (3) review of relevant literature, including a wide range of reports and files; and (4) subsequent analysis of the above-mentioned data to support types of irrigation systems, including descriptions of case examples. All in all, eight main types and fourteen subtypes of irrigation systems were identified in Ghana. The remaining sections of this paper briefly describe the identified systems.

TABLE 1. Ghana Irrigation System Classification.

		Conventional/Emerging
	River	
Formal	Run-of-river diversion-based gravity-fed irrigation systems	C
	River-pumping-based gravity-fed irrigation systems	C
	Run-of-the-river-pumping-based sprinkler irrigation systems	C
	Reservoir	
	Reservoir or storage-based gravity-fed irrigation systems	C
	Reservoir-pumping-based gravity-fed irrigation systems	C
	Reservoir-pumping-based sprinkler irrigation systems	C
	Small reservoir-based communal irrigation systems	C
	Lake	
	Lake–pumping-based sprinkler irrigation systems	C
	Groundwater	
	Traditional shallow groundwater irrigation	C
Informal	Private smallholder systems	E
	Group or communal smallholder systems	E
	Reservoirs	
	Small reservoirs/dugout-based private irrigation systems	E
	Lakes	
	Groundwater	
	Seasonal shallow groundwater irrigation systems	E
	In-field seasonal shallow-well irrigation systems	E
	Riverine shallow-well systems	E
	Permanent well irrigation	E
	Shallow-tube well irrigation systems	E
	Borehole irrigation systems	E
	Domestic wastewater and storm water	C
	Water capture	
	Recession agriculture or residual moisture irrigation	C
	Lowland/inland valley rice water capture systems	E
Large-scale commercial	Large-scale or commercial systems	E
	Public-private partnership-based commercial irrigation systems	E

TYPOLOGY OF IRRIGATION SYSTEMS

The irrigation system typologies observed in Ghana may be broadly classified into two groups based on their current level of formalization. These are (1) the conventional systems, which are mainly initiated and developed by the Government of Ghana or various NGOs; and (2) the emerging systems. The conventional systems are largely supply driven. They are developed with an intention to meet multiple objectives including the attainment of food security, domestic water supply, livestock watering, etc. The emerging systems are those irrigation systems initiated and developed by private entrepreneurs and farmers, either autonomously or with little support from the government and/or NGOs.

Conventional Irrigation Systems

Public Surface Irrigation Systems

There are 22 irrigation schemes presently under this category, and a further number of planned and ongoing projects. These schemes are basically operated and maintained by GIDA or ICOUR where beneficiaries are charged an irrigation service fee for the service rendered in the delivery of water. The schemes can be further classified into seven subtypes based on the source of surface water, the type of power used for abstraction, conveyance and distribution of water, and the in-field water application technology. The identified subsystems are:

Run-of-river Diversion-based Gravity-fed Irrigation Systems: In this sub-typology, a weir diverts water into a main canal that flows under gravity to the fields, mainly paddy fields. There are two such schemes namely, Sata in Sekyere District of the Ashanti Region and Anum Valley in Ejisu–Juabeng District of the Ashanti Region.

Reservoir or Storage-based Gravity-fed Irrigation Systems: In this system, water from an earth dam or reservoir system is diverted to the fields by gravity through intake structures and canal systems. There are eight irrigation schemes under this sub-typology. These are Afife in Ketu District of the Volta Region; Bontanga and Golinga in Tolon-Kumbungu District of the Northern Region; Tono and Vea in Kasena-Nankana and Bolgatanga districts, respectively, of the Upper East Region; Ashaiman in the Ashaiman District; Kpong in Akuse District of the Greater Accra Region; and Okyereko[1] in the Gomoa East District of the Central Region.

Tono and Vea schemes are under the management of ICOUR, which provides credit packages to farmers in the form of machinery hire services and input supply. However, considerable proportions of farmers use animal traction or even hoes for tilling the land.

Lake–pumping-based Sprinkler Irrigation Systems: There are different configurations of these systems, depending on whether the pump is fixed or mobile, and whether an intermediate storage reservoir is involved between intake at the lake and actual sprinkling of water in the field. There are about four schemes under this system. At the Weija Irrigation Scheme in the Ga District of the Greater Accra Region, water is pumped from an intake at the Weija Lake into an open canal that flows under gravity to feed a reservoir. Second pumping is done to send water to sprinklers on the field. At the Kpando-Torkor Irrigation Scheme, in the Kpando District of the Volta Region, the water is pumped from Volta Lake directly to a sprinkler system. In the Amate and Dedeso Irrigation schemes in Kwahu South and Fanteakwa districts, respectively, of the East Region, pumps are moved constantly from one set location to another to pump water from the Volta Lake to irrigate the fields by a sprinkler system.

Run-of-the-river-pumping-based Sprinkler Irrigation Systems: In these systems, pumps draw stored water from a concrete weir and send it to a sprinkler system, which irrigates the fields. There are three such systems namely, Subinja and Tanoso in Wenchi and Techiman districts, respectively, of Brong-Ahafo Region, and Akumadan in Offinso North District of the Ashanti Region. Figure 1 shows the Akumadan Irrigation Scheme under rehabilitation.

[1] Okyereko is occasionally supplemented by pumping water from a river through buried pipes over a distance of one kilometer.

Akumadan Weir Pump house

FIGURE 1. Akumadan Irrigation Scheme under rehabilitation (*Photo credit*: Regassa Namara).

Reservoir-pumping-based Sprinkler Irrigation Systems: Mankessim is the only irrigation scheme under this category. The scheme is located in Mfantsiman District of the Central Region of Ghana. The system is based on an earth-filled dam designed for gravity and sprinkler irrigation. Pumps deliver irrigation water to a sprinkler system.

Reservoir-pumping-based Gravity-fed Irrigation Systems: This system is observed at Dawhenya in the Dangme West District of the Greater Accra Region. In these schemes, a main dam feeds water into a night storage reservoir through an electric pumping system. Water is then delivered to paddy fields under gravity through a canal system. However, at Kpong, only a limited amount of pumping into night storage reservoirs is done to enable irrigation at high levels.

River-pumping-based Gravity-fed Irrigation Systems: In these systems, water is pumped from a river through canals or buried pipes over a distance into a reservoir, which then flows under gravity through main canal systems to irrigate mainly paddy fields. There are two such systems in Ghana namely, the Aveyime Irrigation Scheme in North Tongu District of the Volta Region and Kikam in Nzema East District of the Western Region. Currently, Kikam is not functioning and Aveyime has not been functioning since 1998 and is under rehabilitation. Figure 2 shows the river pumping irrigation system at Aveyime.

Altogether, farmers in the above described schemes number approximately 10,848. The schemes together have a potential area of about 14,699 ha of which only 8,745 ha (59.5%) are developed for irrigated farming (JICA-MoFA 2007). Due to inadequate and deteriorated facilities at the various project sites, the actual land area that is put to use (cropping) has been changing from season to season and, at times, has been dwindling. Only about 7,185 ha (82.2%) of the developed area are currently in use. Schemes such as Kikam, Aveyime, Amate, Anum Valley, Akumadan and Weija are either completely out of production or operational only during the wet season. Most of the non-functioning or underperforming schemes are pump based.

The average cost per hectare of development of these schemes is above US$15,000. Elsewhere in Africa, e.g., the White Nile Pump Irrigation Scheme in Sudan and the Central Tunisia Irrigation Project, the development costs are US$1,000/ha and US$3,400/ha, respectively. In India, irrigation schemes cost as low as US$450/ha. This proves that there is room for reducing the cost of irrigation development in Ghana. Data on the cost of irrigation development in Ghana is patchy, but the generally high cost of irrigation could be attributed to several factors (see Box 1).

Water source | Pump house | Intake valve

Reservoir (night storage) | Main canal | Command area

FIGURE 2. River pumping irrigation at Aveyime (*Photo credit*: Regassa Namara).

BOX 1

Plausible Reasons for Higher Cost of Irrigation Development in Ghana

1. Inadequate local expertise in planning, designing and construction of irrigation projects and, hence, the involvement of expensive expatriate expertise at all stages of the project cycle at the early stages of nationhood.
2. Inadequate feasibility studies leading to costly design changes during construction.
3. Costs of constructing on-farm works.
4. Delays in obtaining imported inputs (owing to foreign exchange shortage during the 1960s to the 1980s) which caused delays in the construction of projects and, hence, an increase in the cost.
5. Unsuitable and avoidable mechanization of construction operations where labor-intensive techniques could be developed and used.
6. The use of tied external funds to build irrigation networks often involving additional supervision and administrative costs and the procurement of non-standard equipment requiring special maintenance and service arrangements.
7. The relative inflexibility in project construction due to agreements entered into by governments and lending agencies.
8. The use of foreign firms for construction and their practices of over-designing in order to preserve their reputations and to compensate for their lack of knowledge of local conditions, and the tendency to include additional costs into their bids to account for risks, which they believe entail operations in Ghana.

Small Reservoir-based Communal Irrigation Systems

Small reservoir systems are usually initiated and financed by donors and designed or constructed by GIDA or private contractors. The contribution of the community towards the development of these systems is substantial. After completion of construction, Water User Associations (WUAs) are established for managing and performing operation and maintenance activities. Small reservoirs are further classified into two sub-groups namely, small dams and dugouts. The main distinguishing attributes are: size, priority of water use, structural details and their management system. Dugouts are smaller in surface area, the volume of water they impound and the number of beneficiaries. The water bed of dugouts are scooped to create more depth and to impound more water. Unlike the small dams, dugouts have no intake structures, canals and laterals. Dugouts usually serve one to two villages, and are planned primarily for domestic and livestock with limited use for irrigation. They are constructed mainly with the help of the District Assembly in locations where other forms of domestic water supply are non-existent or where appropriate dams cannot be constructed due to topographic unsuitability. Small dams and dugouts are found commonly throughout Ghana's ten administrative regions.

Systematic and detailed studies have been carried out on small dams and dugouts in the Upper East Region of Ghana (Birner 2008). The sizes of these systems (and implicitly the volume of water impounded) range from 3 to 30 ha and they are used for livestock, irrigation, fishing and domestic water supply. Thousands of small reservoirs are estimated to exist in Ghana. Knowing the exact number of this infrastructure has been a problem because there is no organization centrally responsible for monitoring these reservoirs. NGOs and donors such as International Fund for Agricultural Development (IFAD), Plan Ghana, Red Cross and Action Aid have been involved in the promotion of these systems starting as far back as the 1970s and 1980s. Recently, GIDA together with the Ministry of Food and Agriculture (MoFA) conducted a survey to have an inventory of the extent of small dams and dugouts for the entire ten administrative regions of Ghana. In these regions, they have identified 786 small dams and 2,606 dugouts. Table 2 shows a summary of dams and dugouts in districts and regions in Ghana.

There are several notable projects heavily engaged in the promotion of these systems, which include Land Conservation and Smallholder Rehabilitation Project (LACOSREP I), LACOSREP II, and UWADEP. All of these were operating in the Upper West, Upper East and Northern regions of Ghana. LACOSREP I, UWADEP and LACOSREP II planned to put into operation a total of 106 small reservoirs (26 in Upper West, 80 in Upper East) for dry season irrigation, fishing and livestock watering, bringing benefits to over 100,000 households. However, only a total of 90 small dams and reservoirs have been constructed and put into operation, thereby developing about 1,000 ha of irrigated land. Moreover, only 132 ha out of the 1,000 ha are new developments and the rest are

TABLE 2. Summary of the number of dams and dugouts in districts and regions (*Source*: GIDA-MoFA 2008).

No.	Region	Number of small dams	Number of Dugouts	Total small dams and dugouts	Cultivated area (ha)
1	Greater Accra	35	218	253	120.0
2	Upper West	84	54	138	712.0
3	Upper East	149	129	278	895.0
4	Eastern	75	115	190	438.0
5	Volta	167	136	303	103.0
6	Central	23	265	288	342.0
7	Ashanti	22	219	241	677.0
8	Western	50	783	833	820.0
9	Brong-Ahafo	50	289	339	1,360.0
10	Northern	131	398	529	649.0
	Total	786	2,606	3,392	6,116.0

rehabilitations of existing dams. The projects brought together about 50,000 households into WUAs (IFAD 2007). The systems developed by these projects use open channel irrigation methods, which waste considerable quantities of water. 'Closed' systems are now being introduced to the latest dams developed by LACOSREP II.

The total estimated area irrigated by these systems is about 6,116 ha (Table 2), which is almost similar to the area irrigated by the 22 public irrigation schemes described in the preceding section. It is widely believed that the number of small dams and dugouts is greater in the three Northern regions of Ghana as compared to the rest of the regions. But the information depicted in Table 1 shows otherwise. The highest number of small dams is recorded in the Volta Region, followed closely by the Upper East and Northern regions. The highest number of dugouts is recorded in the Western Region followed by the Northern and Central regions. Overall, the highest concentration of dams and dugouts is observed in the Western Region, followed by the Northern, Volta and Bron-Ahafo regions. In terms of irrigated area, Eastern, Brong-Ahafo, Volta and Ashanti standout prominently.

In general, reliable data on small-scale irrigation systems are lacking as only a few small reservoir systems have been technically monitored or have had their performance analyzed. Better data and information is available on small reservoir systems in the Upper East Region because some projects have been engaged in monitoring and evaluating these systems. Even in this relatively well-studied region, the numbers do not always converge. According to van de Giesen et al. (2002) there are about 160 small reservoirs in the region, while Birner (2008) found a different total of 126 small reservoirs in the Upper East Region based on a field survey and the use of remote sensing tools, which is also different to the estimate of the GIDA-MoFA (2008) study. The majority of reservoirs in the Upper East Region was built in - or prior to - 1980, while the exact construction date of some 18 small reservoirs could not be determined. In 57.9% of these schemes no irrigation activity was observed during 2006. Irrigation in the command area has been observed in only 23.8% of the schemes, while in 18.3% of the schemes the farmers did some sort of irrigation activity in the catchment area of the reservoirs, and not in the command area. The incidence and intensity of irrigation activity is higher in reservoirs constructed or rehabilitated during 1994 to 1999. Of the 23 small reservoirs constructed during this period, irrigation activity was recorded in 73.9% of the sites (i.e., 13.1% of the cases in the reservoir catchment area and 60.9% of the cases in the command area). Irrigation activity was lower in the new set of schemes (constructed during 2000 to 2006) and also in the very old schemes (constructed in - or prior to - 1980).

The small reservoirs are faced with significant physical, social and institutional/organizational problems. These are: breakage of canals, choking of canals with weeds, delay in the construction of the systems beyond the planned schedule for completion, and institutional issues such as lack of organizations for managing and sustaining the schemes. For instance, the presence of WUAs could be identified only for 31 of the 126 small reservoirs visited in the Upper East Region (Birner 2008). In the 31 reservoirs for which WUAs were available, the participation of farmers in the design, construction and management of the infrastructure was limited (Birner 2008). To illustrate the technical details of small reservoir systems, two case examples of small reservoirs from the Upper East Region namely, Tanga and Weega reservoirs, were taken. The salient features of these reservoirs are summarized in Boxes 2 and 3.

At a high market price, the Weega system is almost twice as profitable as the Tanga system. It can be conjectured that this relatively high profit per volume of water is a result of the trench irrigation technique and the improved management structure in place at the site. Furthermore, as the irrigation method and management structure are results of the overall water availability; the higher profitability of water is, therefore, ultimately a result of this lower water availability. During the study year, farmers producing crops under irrigation at Tanga and Weega sites did not experience

BOX 2

Case Example 1: Tanga Small Reservoir System in the Upper East Region

The Tanga Reservoir, which is part of a cascading reservoir system, has a surface area of 10.6 ha (Liebe 2002), of which 1.6 ha is under cultivation. In 2006, 73 farmers maintained plots at this site. Tanga is located approximately 4.5 kilometers (km) south of the town of Zebilla, in the Bawku West District of the Upper East Region. The dam construction was administered by the NGO, 'Action Aid', reportedly in the late 1980s. The reservoir systems collect surface runoff during the wet season, and typically have enough water till the end of the dry season to provide sufficient water for livestock and also serve basic domestic needs. The reservoir also typically fills to a full supply level every season, so that overflow is released through an emergency spillway. Water is delivered from the reservoir to the cropped area by a concrete lined or partially lined, open canal system. These canals are filled by operating two adjustable valves controlling two outlets. Two valves release water into the two canals for an irrigation system below the dam. One of the valves is leaking, and both canals are deteriorated and receive only limited maintenance. Irrigation is performed by a trench system or a basin and bucket system. Trench and basin forming, bed preparation and cultivation, are all performed manually with short hoe-like tools. The two main canals distribute water to plots by means of turn-outs spaced along the length of the canals. These turn-outs can be plugged with mud or rocks if a farmer does not want to irrigate his or her fields, and opened if irrigation water is needed.

Once the water passes through a turn-out, the vast majority of irrigation is accomplished by first digging circular basins (approximately 2 meters in diameter and 1.5 meters deep) in each farmer's enclosure and then digging a trench to connect the basin to the canal. The water then flows through the turn-out and fills the basin while the valves are open. The farmer then transfers the water from the basin to the crop with a bucket or calabash. Irrigation water is typically released in the evenings, every day, for approximately 2 hours. Farmers' plots are chosen in irregular shapes and sizes, and spread across the area below the dam. The average farmer's plot size at the Tanga site was 0.022 ha. The strip of land extending away from the dam, and at the lowest point between the canals, stays saturated year-round from seepage from the dam and irrigation drainage. There is a weak water-user's association (WUA) in place at this dam and the fee for a plot is relatively inexpensive (US$1.08). The farmers build their own mud walls surrounding each individual plot to prevent animals from entering the cultivated areas.

Both crop selection and management tasks are performed by the farmers themselves and a farmer-comprised WUA. These WUAs elect a small number of officials to carry out fee collection and management decisions. All farmers cultivating a plot within the irrigation system are asked to pay a set fee, per plot, to the WUA. The fees collected are then saved to be used for canal repair and maintenance. As is the case with the majority of small reservoirs in this region, these were built with the financial and technical assistance from a NGO.

Onions, tomatoes and a few other vegetables, such as okra and leaf vegetables for soups, are grown during the dry season in the irrigated areas. Onions are the primary crop and are typically transplanted in early January and take 3 months to mature. They are grown in beds approximately 1.5 meters (m) wide and 5 to 20 m long. The onions provide the largest income, while the various other crops provide supplemental food for the home or small profits at local markets. A total of 1.622 ha has been under irrigation. The total water supplied during the season for irrigation was 53,366 m^3. The water released per cultivated area was 32,901 m^3/ha. The total water supplied to the system relative to the demand, also known as Relative Water Supply, was 5.71.

The profitability of irrigated farming in the scheme was calculated under three crop price assumptions or expectations, i.e., low, medium and high price assumptions for crops produced during 2006. Low price, which is about US$8.6, is common during April. Medium price, which is about US$17.2, is expected in May. High price, which is about US$43.0, is likely in the months following May, if the onions can be stored. The profits were calculated per hectare of land and per cubic meter of water involved in production.

Irrigated crop production was profitable only under high crop price expectations. The low profitability figure may be attributed to the high input costs. In 2006, farmers spent an average of about US$1,688 per hectare. The costs of fertilizer, pesticide, seed and other inputs were US$961, US$80, US$599 and US$48, respectively.

(*Source*: Faulkner 2005)

BOX 3

Case Example 2: Weega Small Reservoir System in the Upper East Region

The Weega Reservoir, which is a stand-alone system not connected to other reservoirs, has a surface area of 11.9 ha (Liebe 2002), and the total area under cultivation in 2006 was 6.0 ha. About 241 farmers maintained plots at this study site. The dam construction was administered by the Red Cross, reportedly in the mid-1980s. The canals (lined and unlined) are maintained fairly well, and are both extended using hand-dug earthen canals. Two valves release water into as many canals as possible, in the irrigation system below the dam. The two main canals distribute water to plots by means of turn-outs spaced along the length of the canals. These turn-outs can be plugged with mud or rocks if farmers do not want to irrigate their fields, and opened if irrigation water is needed. At this study site, a turn-out can service many farmers' fields; therefore, farmers also control water by using earthen barriers across the turn-out trenches to direct water onto their individual plots. The irrigation method at this site is quite different from the method at the Tanga Reservoir. Irrigation water is directed through a turn-out into a turn-out trench, and then diverted by the earthen barriers onto a plot and into small trenches that are dug in-between each individual bed. The water is then thrown/splashed up onto the beds by a farmer with a piece of calabash. This results in a great deal of water not being used and flowing to the middle of the irrigated area, where it forms a drainage stream exiting the fields. Irrigation releases are fairly regular, and occur daily in the evenings for approximately 3 hours.

Farmer's plots are chosen in fairly regular shapes and sizes and spread across the area below the dam, occupying almost all the areas that are potentially cultivable. The average farmer's plot size at this study site was 0.025 ha. The strip of land extending away from the dam, and at the lowest point between the canals, stays saturated year-round from seepage from the dam and irrigation drainage.

There is a well-formed WUA in place at this dam, with the fee for a plot being relatively inexpensive for men (US$1.08), and cheaper for women (US$0.86) who are part of a women's group that lobbied the Red Cross for the construction of the dam. The fees are deposited in a bank account and are to be used when maintenance or repairs are needed. The farmers all work together and build a single mud wall around the entire irrigated area. This works well when all the farmers are still tending to their onions; however, when some farmers harvest, animals can break the wall adjacent to the now-empty plot, and then the animals have access to all unguarded plots. When a breach occurs, it results in a rush to harvest, whether the onions are mature or not.

The total area cultivated was 6.0069 ha. The total water supplied to the system during the season was 68,268 m^3, which translates into 11,365 m^3/ha. The total water supplied relative to demand or 'Relative Water Supply' was 2.4. Thus, water availability is generally not an important factor affecting irrigation performance. The profitability analysis per unit of land shows that crop production is profitable under medium- and high-price assumptions. Positive profit was recorded only at a high-crop-price assumption, when the water input is considered.

(*Source*: Faulkner 2005)

a significant profit, particularly under low and medium market price assumptions. Although these data offer a general range of profits, they are likely to differ from year to year. Disease, drought and input costs all have a negative effect on the profit. The total cost of production was US$945. The costs for fertilizer, pesticide, seed and other inputs were US$457, US$48, US$393 and US$47, respectively. Well-designed storage facilities for onions are likely to increase profits, as they allow onions to be kept and sold in the wet season, when market prices are higher (Faulkner 2005).

The managerial, operational, and environmental factors associated with these systems are all necessary tools to aid in creating a more accurate characterization of their productivity and profitability. The high Relative Water Supply values of both the study sites indicate that water stress was not likely to be a significant factor affecting crop production.

Domestic Wastewater and Storm Water Irrigation

Domestic waste and storm water irrigation in urban and peri-urban areas is quite significant in Ghana. Intensive vegetable production using urban water is a recognized practice, particularly in Accra and Kumasi cities. Urban farmers mostly use water from drains or polluted streams. There are very few farmers in Accra and Kumasi (less than 20) who use raw wastewater as it is commonly understood. Instead, most farmers in urban and peri-urban areas use water which is a mix of various sources including grey water from domestic sources and a large part of storm water run-off or stream water. There are quite a number of donor-driven projects with the twin, and often conflicting objectives of improving the productivity of the systems on the one hand, and reducing the health threat emanating from the consumption of untreated urban irrigated vegetables, on the other. Two types of urban agricultural production systems are noted: (a) open-space production of high-value products on undeveloped urban land, and (b) gardening in backyards of private houses.

The extent of open-space production is estimated to be in the range of 47-172 ha in Accra and 41 ha in Kumasi. Concerning backyard gardening, in Accra alone there are 80,000 small backyards with an estimated area ranging from 50 to 70 ha (Drechsel et al. 2006). Backyard production supports self-employment, income from sales of surpluses and savings on food expenditures. Open-space production, on the other hand, is straight for the market and can be a full-time job. In Accra and Kumasi, the cities supply up to 90% of perishable vegetables (Drechsel et al. 2007). Many of these vegetables are ‘exotic’ ones, and not part of traditional diets. But with increasing urbanization, dietary practices also change -- street vendors selling fast food purchase 60% to 83% of the lettuce available in the markets, while the remaining share goes to restaurants, canteens and hotels. Private households take only about 2% of production in each of the two cities (Obuobie et al. 2006). In spite of the high investment costs needed, irrigated ornamental and flower production is another common and profitable urban and peri-urban agricultural system (Drechsel et al. 2006).

Water-lifting devices commonly used include buckets, watering cans, and treadle and motor pumps. Water application methods in most cases involve overhead irrigation with watering cans or spraying from a handheld hose, while sprinkler and furrow irrigation is seldom, and largely dependent on tenure security (Drechsel et al. 2006). The volume of water used depends on the type of crop, its water requirement and intensity of cultivation. In urban Kumasi, for example, about 600-1,500 millimeters (mm) of water is applied in the year-round irrigation of leafy vegetables, compared to about 200 mm in peri-urban dry-season irrigation (Cornish and Lawrence 2001).

Recession Agriculture or Residual Moisture Irrigation

This type of irrigation is very common around the shorelines of the Volta Lake, the Afram Plains and the Tordize River in the Volta Region. The common crops grown are leafy vegetables, watermelon, okra, chilies, etc. They are usually practiced as supplementary income earning activities to other livelihood strategies such as fishing. The future of these systems is bleak given the recent policy debate regarding buffer zones, which intends to prohibit irrigation within a 50 m reach from a water body. Figure 3 shows fishing communities around the Volta Lake in the Eastern Region of Ghana practicing recession farming during the dry season.

Fishing communities around the Volta Lake often engage in farming based on residual moisture after the lake recedes in the dry season to complement the income they earn from fishing and upland rain-fed agriculture. Households claim ownership to the land inundated by the lake based on the prevailing pre-Aksombo Dam land tenure arrangements. This often creates tension between indigenous population and settlers, who have completely lost their land to the lake.

FIGURE 3. Fishing communities around the Volta Lake in the Eastern Region of Ghana practice recession farming during the dry season (*Photo credit*: Regassa Namara).

Traditional Shallow Groundwater Irrigation

Groundwater irrigation is a sector that is not well understood or explored in sub-Saharan Africa, in general, and in Ghana, in particular. The domestic use of the resource is rather well appreciated and gets substantial funding from various sources. However, the agricultural use of groundwater, specifically that of the shallow aquifer, is not a new phenomenon in Ghana. For instance, in the Keta Strip of the Volta Region, farmers' experience of groundwater utilization for agriculture is well over 200 years. Different power sources are used to lift water. These include human feet/hand-operated equipment, such as rope, calabash and buckets. However, the traditional labor-inefficient shallow groundwater irrigation systems are giving way for the more intensive systems discussed in the next section. These systems have emerged due to the introduction of electric, diesel, petrol, solar and wind-powered engines.

Emerging Irrigation Systems

Groundwater Irrigation Systems

The agricultural use of groundwater is on an increasing trend in Ghana. Shallow groundwater irrigation is an old tradition in the Keta Strip and is increasingly becoming significant in the White Volta Basin of the Upper East Region. The application of shallow groundwater irrigation in the Northern regions of Ghana goes back to the 1960s, but more and more hand-dug shallow wells are being developed throughout the upper parts of the White Volta Basin in the last 10 to 15 years, particularly in the Atankwidi watershed. The main constraints to the development of groundwater-based irrigation are drilling technology, costs of development and lack of energy. There are different sub-typologies of groundwater irrigation namely, seasonal shallow-well systems, permanent shallow-well systems, shallow-tube well systems and communal borehole systems. Each of these groups is dominant in specific agroecological, socioeconomic and institutional (mainly land tenure) settings. Seasonal shallow-well irrigation systems are dominantly found in the Upper White Volta Basin, while permanent shallow-well irrigation systems are mainly found in the Keta Strip. Shallow groundwater irrigation is mainly carried out in inland valleys where water is retained in the alluvial material close to the river, so that people can cultivate crops during the dry season. So far, the development of shallow groundwater irrigation has received little support from the government or donors. Nevertheless, it provides farmers and their households with an alternative source of income during the dry season.

Seasonal Shallow Groundwater Irrigation Systems: Seasonal shallow-well irrigation systems are further categorized into two sub-types namely, riverine seasonal shallow-well systems and in-field seasonal shallow-well systems based on their place of occurrence, i.e., whether they are built on a river course or on part of crop fields. In this paper, those built on a river course are named as riverine seasonal shallow-well systems and those that are built in fields are named in-field seasonal shallow-well systems. The systems are visible in very high resolution imagery as white and blue bright spots. The white bright dots are in-field seasonal shallow-well irrigation systems and the blue spots along the river course are riverine seasonal shallow-well systems. Figure 4 shows the in-field and riverine seasonal shallow well systems.

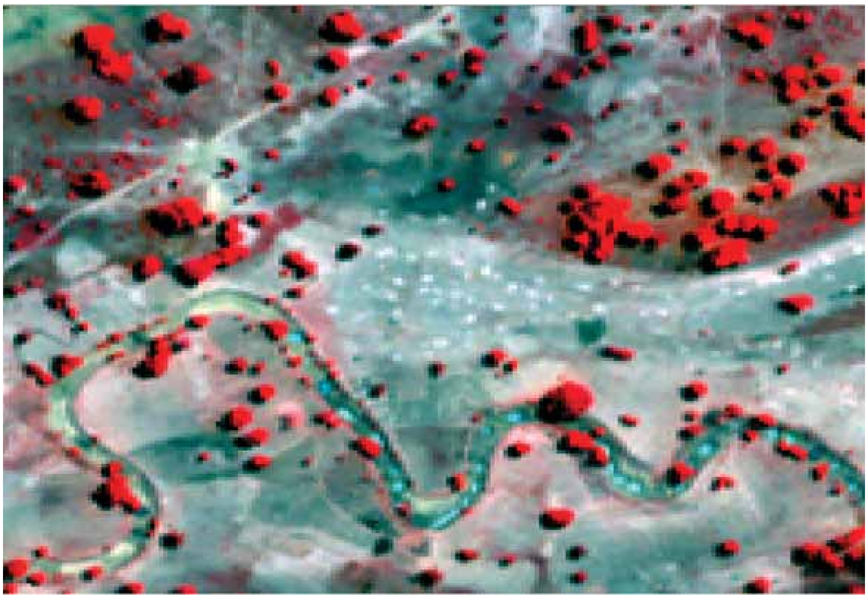

FIGURE 4. In-field and riverine seasonal shallow well systems (Quickbird 2.44 m data for May 5, 2008, shown in FCC (RGB) (*Source*: Gumma 2007).

In-field Seasonal Shallow-well Irrigation Systems: These are dug in low-lying high water table areas mostly close to rivers, swampy areas or even at the tail-end of existing public irrigation schemes (to reuse seepage and drainage water). In the rainy season, rivers flood these wells and fill them with soil and silt. They are de-silted in the subsequent dry season and reused again for irrigation. In other cases, the wells have to be refilled at the end of the dry season and reconstructed at the beginning of the next dry season, because the same field is used for rain-fed cultivation during the wet season. Thus, the wells are constructed in such a way that they will not last beyond the dry season. This is because the same piece of land is utilized for the production of rain-fed crops by the owner of the plot. They are usually 3-6 m in depth and about 0.5-1.2 m in diameter. The diameters of the reopened wells tend to be higher than those of the newly built wells. In-field seasonal shallow wells can irrigate an area of about 200-1,000 square meters (m^2) and are visible in very high resolution imagery as white bright spots (Figure 4). Figure 5 shows the in-field seasonal shallow well system.

Irrigation is carried out during the dry season (January-May). The crops grown are mainly vegetables. During the rainy season (June-October) the same plots will be planted with rain-fed

FIGURE 5. In-field seasonal shallow well system (*Source*: Gumma 2007).

crops such as maize and rice by the owner of the land. Water is lifted from these shallow wells by means of buckets or pumps of different types including foot/hand-operated ones and small motorized pumps to irrigate small pieces of land. Crops are planted or cultivated in a series of ditches or furrows, which are specially constructed in a field. Figure 6 shows crops cultivated in small ditches or furrows.

FIGURE 6. Small ditches or furrows (*Source*: van den Berg 2008).

The depth and width of the ditches vary from 0.10-0.15 m, while the length varies from 0.7-1.7 m. Irrigated fields are located in different places along a river. The sizes of the irrigated fields vary from 200 to 900 m^2. A field size above 1,000 m^2 is rarely found. Many factors contribute to the observed small size of irrigated land. Some of the factors contributing to this are lack of financial resources to buy inputs for cultivation, shortage of suitable land, labor availability and water availability. The number of wells per field varies from 2-3 wells on the smaller fields to 3-5 wells on the larger fields. In some cases, as many as 15 wells per field can be encountered. The distance of the wells from the river varies from 15 to 200 m. In some cases, in-field seasonal shallow wells can also be made at more than half a kilometer distance from the river. The location of the wells is determined on a trial-and-error method; hence, experience in the water availability of previous years is important. The discharge from a well is low, and, as such, it can only irrigate small areas. Figure 7 shows a hand pump being used for irrigation.

FIGURE 7. Hand pump used for irrigation (*Source*: van den Berg 2008).

Riverine Shallow-well Systems: These are practiced on beds of ephemeral rivers. The wells are constructed for dry-season cultivation and have to be reconstructed every season, because the river destroys the structure during the wet season. The size of irrigated plot is higher for riverine shallow-well systems as compared to that of in-field seasonal shallow well systems, particularly when pumps are used instead of buckets because application of water is less labor-intensive. Figure 8 shows the riverine shallow-well system.

Water is taken by means of buckets or pumps onto small pieces of cultivated land. The farmers, however, are able to irrigate larger areas if they have a pump. Farmers dig one or two wells of about 10-100 m^2 with a starting depth of 0.5-1.5 m, and deepen the well as the water level decreases during the season up to 6 m below the riverbed level. Some farmers were able to hire people to dig the wells. This type of irrigation is considered to be for farmers who are able to buy a small pump that can be transported on the back of a bicycle.

FIGURE 8. Riverine seasonal shallow well systems (*Source*: Gumma 2007).

Permanent Well Irrigation: These systems are developed closer to the homestead or even in the living compound (e.g., as in Upper West and Upper East regions), near urban centers (e.g., as in Ashanti and Eastern regions) and in fields away from the homestead (e.g., as in Keta District in the Volta Region). When such systems occur in urban or peri-urban settings, they are usually synonymous with irrigated urban and peri-urban farming. The permanent shallow wells can be lined (cement lining) or unlined. Figure 9 shows some permanent shallow wells.

Lined permanent shallow well - Keta | Lined permanent shallow well - UE | Unlined permanent shallow well

FIGURE 9. Permanent shallow wells (*Photo credit*: Regassa Namara).

Farmers prefer the lined ones, but some do not have the financial means to acquire the requisite materials for lining. The unlined wells are irregularly shaped. The depths of the wells range from 1 to 14 m depending on the prevailing groundwater level. The diameters range between 1 to 2 m. Similar to the case of seasonal shallow wells, simple manual tools are used to construct these wells. Thus, the major cost components are human labor and cement for lining. In Northern Ghana regions, the construction cost of a typical unlined permanent shallow well is about US$36.6. The number of wells per unit area varies widely from region to region - it ranges from as low as 2 wells to about 100 wells per hectare as observed in the Keta Strip. Permanent shallow wells are used throughout the year mainly for vegetable farming, domestic use and livestock watering. Diverse technologies are used for lifting and distributing water from the wells including rope and bucket, rope pump with bucket and motorized pumps.

This type of irrigation system is most common in the Keta Strip of the Volta Region along the fringes of lagoons and depressed areas. A total of 34,263 wells are recorded in the Keta District, irrigating an area of 1,052 ha. The principal crops produced are vegetables, mainly shallots (GIDA-MoFA 2008). Table 3 shows a summary of wells and areas under irrigation along fringes of lagoons and depressions in the Keta District.

TABLE 3. Summary of wells and areas under irrigation along fringes of lagoons and depressions in the Keta District (*Source*: GIDA-MoFA 2008).

Location	No. of wells	Area under irrigation (ha)
Anloga	12,272	452
Anyanui-Dzita Agbledome	10,864	268
Atorkor Srogbe Whuti	5,187	132
Woe	4,057	111
Tegbi	1,883	89
Total	34,263	1,052

In the Keta Area, permanent shallow-well irrigation has received support through different projects. For instance, the Agricultural Sector Investment Program (ASIP) provided funds to farmers' groups for the construction and mechanization of about 1,500 new wells and those already in existence within the Keta Strip. In late 1999, the Food and Agriculture Organization of the United Nations (FAO) began a pilot project on irrigated horticulture in Ghana through the Special Program for Food Security (SPFS). This component, managed by Enterprise Works (EW), began with the importation of 40 treadle pumps from Benin in West Africa. Prior to importation of the pumps, farmers irrigated their fields using water drawn from wells with a rope and bucket.

Shallow-tube well Irrigation Systems: Shallow-tube well irrigation systems are commonly found in the Volta Region, specifically in the Keta Strip. They are individually owned and used for irrigation and domestic purposes. Land developed for this kind of irrigation is mostly family land. The cost of developing a shallow tube well and its water distribution system is about US$246.5, as at 2007. The irrigated area ranges between 0.21 and 0.81 ha. Depth of a tube well ranges from 6 to 9 m and water is lifted mainly through electrically powered, 5–7 horsepower (HP) pumps fixed near the tube wells. Figure 10 shows the tube well technology.

Electric pump

Tube well irrigation in the Keta Strip

FIGURE 10. Tube well technology (*Photo credit*: Regassa Namara).

Cost of using electricity to pump water is about US$35.2 per month. Water application to the fields is via sprinklers or hose. The irrigation system is operated and maintained by individual farmers. In Ghana, there is potential to develop both shallow and deep groundwater systems for irrigation and other uses, but precaution must be taken to prevent these systems adversely affecting users of existing systems. The tube well technology for small-scale irrigation has proven to be very successful in the Keta Strip. Over the past several years, shallow aquifers have been making an increasing contribution to the expansion of small-scale irrigation. The presence of groundwater resources at shallow alluvial depths, less than 20 m throughout the dry season, plays a key role. More importantly, the introduction of low-cost techniques for the construction of shallow wells has been a major contributing factor. Figure 11 shows a sprinkler head and an electric pump associated with a tube well.

Tube well construction and mechanization have been encouraged by some projects. For instance, ASIP provided funds to farmers' groups for development of shallow tube wells. But, some have shown reservations about expansion of this technology in the Keta Region. For instance, in 1996, the consultants working on a project funded by the UK Department for International Development (DFID), known as 'Participatory Approaches to the Management of the Coastal Zone Ecosystem in Ghana', expressed concern over the construction of several mechanized wells in the Keta

A sprinkler

A farmer fitting an electric pump to a tube well

FIGURE 11. A sprinkler head and an electric pump associated with a tube well (*Photo credit*: Emmanuel Boeke).

Strip without adequate monitoring (Robinson 1998). Their concern was based on the fact that the freshwater was sitting on a large mass of saline water. Any disturbance of the fragile freshwater/saline water interface by uncontrolled large-scale abstraction could erode the freshwater base of the strip. However, in Keta, the introduction of low-cost shallow-tube well technology combined with small engine-driven water pumps triggered the development of irrigation. The tube well technology is much cheaper than public irrigation. Individual farmer's ownership of the wells and the pump sets provides considerable independence in selecting crops and times of planting, which is not usually the case in the public or communal surface irrigation systems of Ghana. It also allows for the adjustment of irrigation schedules in accordance with observed crop needs rather than restricting farmers to the strict rotation of public surface irrigation schemes.

Borehole Irrigation Systems: Borehole irrigation systems refer to systems developed to abstract and utilize water from deep aquifers, unlike shallow-tube well irrigation systems that are based on shallow aquifers or subsurface water resources. In other words, a distinction is made between shallow tube wells and boreholes depending on the nature of the recharging system and the depth of water. Boreholes are deeper and rely on aquifers for their recharge, while shallow tube wells are shallower in depth and rely on subsurface water for their recharge mechanism. The extent of borehole irrigation systems is not yet determined but there are indications that the system has potential. The main limiting factors for the expansion of borehole-based irrigation in Ghana may be the inadequacy of groundwater yield and the cost of development and maintenance of the system. It is generally known that the deeper a well, the higher its construction costs and the cost per unit volume of water abstracted, irrespective of the type of water-lifting device used. For these reasons, in Ghana, the use of groundwater for irrigation, especially from deep aquifers has not been very successful.

There are indications that these systems are being used in Volta, Greater Accra and Central regions of Ghana and, to a lesser extent, in Upper East and Upper West regions. Boreholes are usually sunk to withdraw water for domestic use. Many boreholes developed with such an objective in mind have been abandoned because the quality of the accessed water was not fit for home consumption (drinking). Such boreholes are being customized to be used for irrigation purposes.

Pilot communal borehole irrigation systems were developed in the Upper East, Upper West and Northern regions in 2000 under MoFA's Village Infrastructure Project, which is funded by the World Bank and Kreditanstalt für Wiederaufbau (KFW). A windmill pump and 50 m^3 ferro-cement water storage facility were constructed at existing borehole sites, with a yield of about 1.5 liters per minute promoting the use of wind energy, but have never been operationalized in the Upper East and Upper West regions. The 5 m Poldaw wind pump on the scheme, when operational, lifts water from a depth of about 80 m into a storage reservoir. The storage reservoir is 1.83 m high, relative to the ground. Water from the reservoir is allowed to flow freely under gravity with the help of the main outlet valve, which is installed close to the reservoir, and a supporting valve or a control valve, which is installed 150 m away from the storage reservoir. Figure 12 shows a wind pump in the Northern region of Ghana.

FIGURE 12. A wind pump in the Northern region of Ghana (*Photo credit*: Gordana Kranjac-Berisavljevic).

River Lift Irrigation Systems

Private surface water pumping or lift irrigation systems are on the increase in Ghana. These systems are categorized into three main typologies: 1) private smallholder systems; 2) group or communal smallholder systems; and 3) large-scale or commercial systems. The use of low-cost motorized pumps in the peripheries of the established public irrigation systems is a common phenomenon in Ghana. Farmers use seepage and drainage water from the schemes to produce vegetables. When such schemes fail to function (as in the case of the Ochereko Irrigation Scheme) or are under major rehabilitation (as in the Tono Irrigation Scheme) farmers make use of the available water by using pumps. These systems are located along perennial rivers, predominantly along the White Volta River but also spreading to the Black Volta, Oti and Dakar rivers. They are concentrated in the Upper East, Upper West, Northern, Eastern and Volta regions. They are also spreading to Brong Ahafo and Ashanti regions. The size of irrigated area per person, by these systems, ranges from 0.4 to 99.2 ha. They are characterized by a high cropping intensity, e.g., three times a year.

In the Upper East Region of Ghana, the flow level of the White Volta River is mainly regulated by the Bagré Dam in Burkina Faso, which causes a continuous discharge during the year (Ammerlaan et al. 2005; Poolman 2005). In this way, it allows people living close to the river to irrigate their land during the dry season by means of smaller or bigger pumps.

Private Smallholder Systems: In this system, individual farmers use small petrol or diesel pumps to pump water from nearby rivers, streams, to their fields. This practice is also found in urban areas where farmers increasingly use pumps to collect water from usually polluted streams or drains while others fetch water with cans manually (as was already discussed in the section, *Domestic Wastewater and Storm Water Irrigation*). Pumps may also be accessed through rental arrangements. Motor pumps with 3.5 to 10 HP engines were commonly used. Petrol engines are the most common types. Typical farming community in Ashanti, Eastern and Brong Ahafo will have about five pumps. Most farmers own just one pump, with a few owning two, and they purchase the pumps from the nearby major towns such as Kumasi, Accra, Bolga, Tanoso, Techiman, etc. Some farmers claimed to have accessed the pumps from as far as Nigeria and Sankasi in Togo. Figure 13 shows small pumps and their accessories at a shop in the Northern Region.

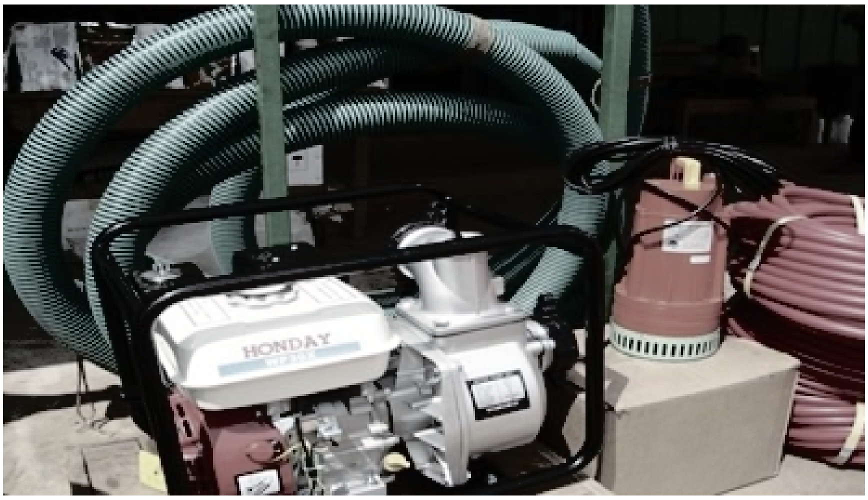

FIGURE 13. Small pumps and their accessories at one of the shops in the Northern Region (*Photo credit*: Regassa Namara).

Although not in the project design, pumping water from the White Volta River for riverside horticulture was introduced in the final year of LACOSREP II project in the Upper East Region. Gardens along rivers in the Upper West Region using hand irrigation and small pumps is becoming common. It allows cultivation of three crops per year, therefore, significantly increasing farmers' income. This method is simple and effective, but requires pumps and fuel as inputs. Provision of credit facilities could rapidly extend the benefits to a wide range of farmers, as has been shown in other countries such as Nigeria. It is recommended that adequate attention be given to these cost-effective technological packages.

Group or Communal Smallholder Systems: These systems may be self-initiated by the farmers or initiated by the government (i.e., MoFA) or NGOs (e.g., Sasakawa Global 2000 Programme of the Sasakawa Africa Association). The initiators facilitate group's access to credit for procuring pumps and the necessary accessories. Pumps may also be donated to the group for free by various NGOs or groups. These are usually mobile pumps with sizes ranging from 2.5 to 11.5 HP. In some cases, farmers themselves take the initiative of making a group. The size of the group depends on the number of pumps owned and the size of suitable land for irrigation. The sources of finance for procuring the pumps are 'market women' and the 'Food Agricultural Budget Support Project' of MoFA. The area per household is usually less than half a hectare. The area cultivated usually belongs to other members of the community (i.e., individuals, chiefs, market women, etc.) or collectively owned by the community, and can also be hired or leased.

In addition to pumps, farmers acquire accessories such as pipes to convey irrigation water to the fields. Farmers are organized with well-established leadership and a written constitution. The leadership organizes meetings and manages loans within the organizations. For example, in the Aveyime Area, Volta Region, following the collapse of the Aveyime Irrigation Scheme in 1998, some farmers have acquired small diesel pumps to abstract and use water from the Volta River for vegetable production. These farmers use pumps in rotation and share maintenance costs according to agreed or established bylaws. These mobile pump-based irrigation systems helped the farmers to grow crops of their choice. Such crops are usually vegetables or horticultural crops. It was noted that the farmers who used to benefit from the 'Aveyime Irrigation Project' were dictated to grow only rice.

Large-scale or Commercial Systems: These systems involve the use of high-powered pumps (about 30 HP). In some cases, water is pumped from a river and stored in a small reservoir (similar to the public systems). Pumps are used to deliver water to the field and sprinklers, with the exception of Northern Ghana where drip is used for field application. The main crops grown are teak, oranges, mangoes and cashew, unlike those under public irrigation systems where rice and vegetables are irrigated. In these systems, production is mainly export oriented. The pump owners operate larger farms ranging from 1.2 to 92.2 ha using high capacity or multiple small capacity pumps. Notwithstanding the scale, irrigation practices were similar to the other pumping-based irrigation typologies. The commercial farmers also use high capacity pumps with permanent housing along rivers. Some of the communities or localities where this practice is commonly encountered are Dedeso, Nsawam, Koforidua, Panpanso and Somanya. The commercial or large-scale river pumping schemes usually have out-growers. The nucleus farmers provide the out-growers with key inputs and in return the farmers sell the outputs to the nuclear farmers.

Public-Private Partnership-based Commercial Irrigation Systems

There are few large-scale commercial irrigation systems established as joint ventures between the Government of Ghana and private companies. Examples of such systems include Kpong Farms Limited; the Volta River Estates, which produce banana mainly for export; mango seedling production using water from the Ligba Reservoir; Jei River Farms; and Prairie Volta Limited, etc. These irrigation systems also have out-growers, who receive water and other agricultural support to produce and supply crops of interest to commercial farmers. The systems are largely export oriented. The private companies may have their own irrigation facility or infrastructure. For instance, two foreign companies use drip irrigation to cultivate 1,400 ha of bananas for export. They, however, usually rehabilitate and further improve existing public irrigation systems based on certain agreements.

Prairie Volta Limited has begun work on 1,286.7 ha for rice production at the Aveyime Rice Project. The project initially called the 'Quality Grain Project' had been initiated by the Government of Ghana over 10 years ago with a US$20 million foreign loan. The commencement of the project has been delayed by 8 years. The project owns assets and equipment such as irrigation facilities, a 60-tonne capacity rice mill, 15,000-tonne capacity silo, tillers, planters and harvesters. Figure 14 shows some assets of Prairie Volta Limited.

The company (Prairie Volta Limited) plans to make some of these facilities available to private rice growers in the country and adopt an out-grower program to upgrade and expand the rice industry in the country. The project is expected to significantly reduce Ghana's current

Irrigation water pumps stored at Aveyime

The silos

FIGURE 14. Some of the assets of Prairie Volta Limited (*Photo credit*: Regassa Namara).

annual import expenditure, which amounts to US$450 million. Under the partnership agreement, the Government of Ghana holds a 30% share in the project, while the Prairie Volta Limited and Development Finance Holding Company (DFHC) hold 40% and 30%, respectively.

Lowland/Inland Valley Rice Water Capture Systems

Lowland/inland valley rice is produced in the low-lying areas where conducive or favorable hydrological conditions for paddy cultivation are prevalent. Ghana is endowed with a vast stretch of lowland/inland valleys (including valley bottoms and floodplains) that can potentially be developed for rice cultivation. It is estimated that about 1 Mha of such land can potentially be developed primarily for rice production by employing water management technologies and practices. To realize this potential, two types of water management interventions are promoted. The first intervention involves capturing or harvesting water through the implementation of water regulating structures. Figure 15 shows an example of water regulating structures constructed by projects.

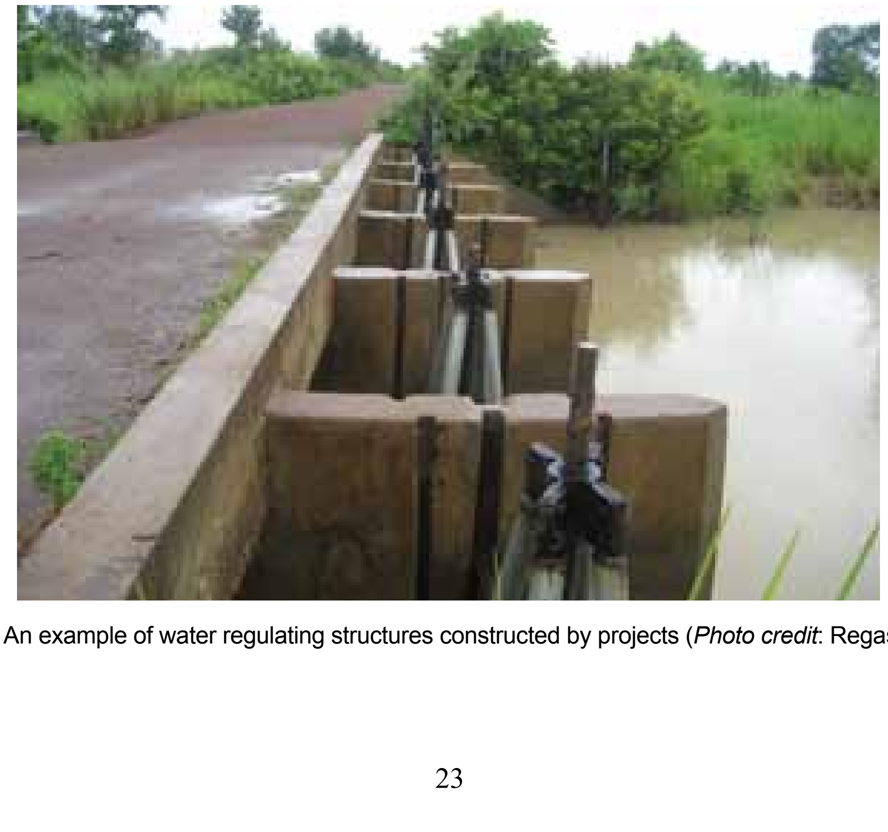

FIGURE 15. An example of water regulating structures constructed by projects (*Photo credit*: Regassa Namara).

This may also involve civil works such as the construction of irrigation and drainage canals. The objective of this is to store or impound enough water during the rainy season for use when the rice crop, which is planted downstream of the water regulating structure, faces any moisture stress. The idea is to intensify rice production through supplementary irrigation. The second set of interventions involves in-field or on-farm land and water management technologies or practices with the prime objective of improving the moisture retention capacity of the soil or the field. Such types of interventions include land clearing, bunding, leveling and puddling. Such practices are labeled 'Sawah systems'.

The Government of Ghana seems to have taken the issue of lowland or inland valley rice development seriously. Cabinet information paper issued on April 15, 2005, stated the program for promotion of domestic rice with a specific development target to be achieved by 2010. The paper stipulates that by 2010, the rice area will be increased by 25,000 ha. About 19,000 ha will be developed in lowlands or in the inland valleys.

Consequently, the Government of Ghana has commissioned some projects, notable among which are the Lowland Rice Development Project (LRDP) and the Inland Valley Rice Development Project (IVRDP). The LRDP had an estimated budget of EUR 267 million, of which EUR 229 million is to be met through financial assistance from the French Government through Agence Française de Développement (AFD). AFD provided a greater part of the funds for the project. Other financial partners included the Government of Ghana, the Agricultural Development Bank (ADB), Accra, Ghana, and the rural farmers of the Northern Region of Ghana. The project was implemented through a collaboration of French and Ghanaian consulting firms, SOFRECO (Consultancy for Sustainable Economic and Social Development), France, and PAB Development Consultants, Ghana, under the overall oversight of the MoFA. This project has two phases. The first phase has been implemented during 1999 to 2003 and was focused exclusively on the Northern Region. In the first phase, some 1,151 ha of inland valley rice systems were consolidated, benefiting about 2,500 households. By the end of 2003, intensive rice cultivation had been practiced by small-scale farmers in three valleys, Sillum, Zuwari and Kulda-Yarong, all within a 50 km radius from Tamale. About 300 women processors from these three valleys were also trained in improved rice processing techniques.

The paddy yield has been improved to 2.6 tonnes per ha (t/ha) with 13% of the farmers achieving 4 t/ha. The second phase, which is already underway, was started in 2008 and will proceed up to 2012. The objective of the second phase is to develop or consolidate about 6,000 ha of lowland/inland valley rice in four regions, Northern, Upper West, Upper East and Volta.

The Inland Valley Rice Development Project (IVRDP), which was financed by the African Development Bank (AfDB), is to be implemented in five regions, Brong Ahafo, Ashanti, Eastern, Central and Western. The project facilitates the forming of groups of farmers and assisting them to engage in lowland paddy production on a basis of 0.5 ha per household. The project includes civil works such as construction of irrigation, drainage canals, land clearing, levelling and bund construction. It also provides technical and managerial support. Land tenure system was found to be one of the major constraints the project faced, particularly in Southern Ghana. Landowners are often reluctant to sign land lease contracts. Land rental cost is 50 kilograms (kg) of milled rice or US$21.1 in cash for 0.5 ha of paddy field per year (JICA-MOFA 2007).

Small Reservoirs/Dugout-based Private Irrigation Systems

This system is common among large-scale plantation farmers. The water is used to produce pawpaw, pineapples, mangoes, cashew, oranges, etc. The water might also be used for livestock watering and rice production. Some of these private reservoirs are also used by the surrounding communities for both domestic and irrigation purposes.

CONCLUSIONS AND RECOMMENDATIONS

Ghana's irrigation sector is often equated to public/communal surface irrigation schemes, particularly to the 22 irrigation schemes managed by GIDA and ICOUR. The current study has revealed or confirmed that irrigation in Ghana is already quite significant as compared to any official statistics. Determining the exact area of irrigated agriculture in Ghana is beyond the scope of this study and is undoubtedly a priority follow-up activity. Diverse typologies of irrigation systems were noted, which can be categorized into two broad classes, conventional and emerging systems. The conventional systems, which were commissioned several years ago, are mainly initiated and developed by the Government of Ghana and NGOs or are developed by communities or individuals. The specific typologies under conventional systems are: public surface irrigation systems; small reservoirs; wastewater irrigation; recession agriculture or residual moisture irrigation; and shallow groundwater irrigation based on traditional lifting technologies.

The emerging systems are those irrigation systems initiated and developed by private entrepreneurs and farmers, either autonomously or with little support from the government and/or NGOs. The emerging systems include: groundwater irrigation systems based on contemporaneous lifting or pumping technologies; river or stream lifting or pumping-based irrigation systems; public private partnership-based systems; out-grower systems; lowland/inland valley rice water capture systems; and private small-reservoir systems. The extent of area of the emerging systems is difficult to establish, but it is believed that the area is many times greater than that of the conventional/public irrigation systems. For instance, two 3.5 HP pumps, communally owned by 100 farmers, irrigated about 20 ha in Ashanti. The corresponding value for two small reservoirs, Tanga and Weega, in the Upper East Region is 7.7 ha, serving about 314 farmers.

The emerging systems are based on access to mobile and flexible pumps. Pumping is based on diverse sources of energy such as diesel, petrol, wind, electricity and possibly solar energy. The water sources are also numerous including groundwater and various surface water sources. The unique attributes of the emerging systems are that they allow farmers to access water on demand and to make autonomous production decisions. Thus, the cropping patterns differ between the emerging and conventional irrigation systems. Whereas high-value crops such as fruits, vegetables and trees are grown under emerging irrigation systems; it is mainly rice that is cultivated under conventional irrigation systems.

Despite their significance and recognition in Ghana's irrigation policy, the emerging irrigation systems get inadequate public support because:

- There is no centralized effort to monitor and regulate the development of the emerging irrigation systems; and
- The extension service is inadequate. In the absence of support from public extension systems, farmers are experimenting to find out appropriate agronomic practices, on-farm water management or irrigation techniques, and crop protection practices unaided.

Thus, it is recommended that an apex body be established with a mandate to monitor, regulate, manage and facilitate the development of the emerging irrigation systems in Ghana. This apex body may be a part of GIDA, but should be entrusted with the added responsibility of providing research and extension support to the dynamic irrigation systems of Ghana.

REFERENCES

Agodzo, S. K.; Bobobee, E. Y. H. 1994. Policy issues of irrigation in Ghana: 1960-1990. *Proceedings of the XIIth World Congress on Agricultural Engineering, Milano, Italy, August 28 - September 1, 1994*. CIGR Vol. 1, pp. 335-343.

Ammerlaan, P.; Bloemendal, M.; Kramer, N.; Rutten, M.; Sanders, M. 2005. Constructive design and maintenance of small reservoirs in the Upper East Region, Ghana. Water Resources Management, Faculty of Civil Engineering. Delft, the Netherlands: University of Technology.

Birner, R. 2008. Can decentralization and community-based development reduce corruption in natural resource management? Insights from irrigation in Ghana and forestry in Indonesia. Paper prepared for presentation at the 13th International Anti-Corruption Conference, Athens, Greece, October 30 – November 2, 2008, International Food Policy Research Institute (IFPRI).

Cornish, G. A.; Lawrence, P. 2001. *Informal irrigation in peri-urban areas: A summary of findings and recommendations*. Report OD 144. UK: HR Wallingford, Water Management Department/UK Department for International Development (DFID).

Drechsel, P.; Graefe, S.; Sonou, M.; Cofie, O. O. 2006. *Informal irrigation in urban West Africa: An overview*. Colombo, Sri Lanka: International Water Management Institute. 34p. (IWMI Research Report 102).

Drechsel, P.; Graefe, S.; Fink, M. 2007. *Rural-urban food, nutrient and virtual water flows in selected West African cities*. Colombo, Sri Lanka: International Water Management Institute. 35p. (IWMI Research Report 115).

Faulkner, J. W. 2005. Water use, productivity, and profitability of small-scale irrigation schemes in Ghana's Upper East Region. Project paper to meet requirement for MS degree in Agricultural and Biological Engineering, Soil and Water Concentration, Cornell University Ithaca, NY.

FAO (Food and Agriculture Organization of the United Nations). 2009. AQUASTAT database. FAO's information system on water and agriculture: Ghana. Available at www.fao.org/nr/water/aquastat/countries/Ghana/index.stm

GIDA (Ghana Irrigation Development Authority)-MoFA (Ministry of Food and Agriculture). 2008. *Area under irrigation in Ghana*. Unpublished report.

Gumma, M. K. 2007. Shallow ground water irrigation in Atankwidi Watershed, Ghana.

IFAD (International Fund for Agricultural Development). 2007. Knowledge profiling: Promoting easy access to knowledge and experience generated in projects and programs. Rome, Italy: IFAD.

IWMI (International Water Management Institute). 2007. *Recognizing informal irrigation in urban and peri-urban West Africa*. Colombo, Sri Lanka: International Water Management Institute (IWMI). 6p. (IWMI Water Policy Briefing 026). Available at www.iwmi.org/Publications/Water_Policy_Briefs/PDF/WPB26.pdf

JICA (Japan International Cooperation Agency)-MoFA (Ministry of Food and Agriculture). 2007. The study on the promotion of domestic rice in the republic of Ghana. Progress Report 2. Nippon Koe Co. Ltd.

Kyei-Baffour, N.; Ofori, E. 2006. Irrigation development and management in Ghana: Prospects and challenges. Department of Agricultural Engineering, Faculty of Mechanical and Agricultural Engineering, College of Engineering, Kwame Nkrumah University of Science and Technology (KNUST), Kumasi, Ghana.

Liebe, J. R. 2002. Estimation of water storage capacity and evaporation losses of small reservoirs in the Upper East Region of Ghana. Diploma thesis, University of Bonn, Germany.

Obuobie, E.; Keraita, B.; Danso, G.; Amoah, P.; Cofie, O. O.; Raschid-Sally, L.; Drechsel, P. 2006. *Irrigated urban vegetable production in Ghana: Characteristics, benefits and risks*. Accra, Ghana: International Water Management Institute (IWMI); Resource Centres on Urban Agriculture and Food Security (RUAF); CGIAR Challenge Program on Water and Food (CPWF); International Development Research Centre (IDRC). pp. 150. Available at www.cityfarmer.org/GhanaIrrigateVegis.html

Poolman, M. I. 2005. Developing small reservoirs - A participatory approach can help. Master thesis, section Policy Analysis, Faculty of Technology, Policy and Management, Technical University of Delft, Delft, the Netherlands.

Robinson, G. S. 1998. A study of the Keta Strip shallow aquifer, Ghana. MSc. Thesis. Bangor, UK: Centre for Arid Zones Studies (CAZS), University of Wales.

Smith, M. 1969. *A historical sketch of water resources development in Ghana*. Accra, Ghana: Council for Scientific and Industrial Research (CSIR)-Water Research Institute (WRI).

van den Berg, J. 2008. *Exploring shallow groundwater irrigation: Current status and future application*. A case study in the Atankwidi catchment, Ghana. MSc Thesis final report. Delft, the Netherlands: Delft University of Technology.

van de Giesen, N.; Kunstmann, H.; Jung, G.; Liebe, J.; Andreini, M.; Vlek, P. L. G. 2002. The GLOWA Volta Project: Integrated assessment of feedback mechanisms between climate, land use, and hydrology. In: Climatic change: Implications for the hydrological cycle and for water management, Beniston, M. (ed.), *Advances in Global Change Research* 10: 151-170. Dordrecht, the Netherlands: Kluwer Academic Publishers.

World Bank. 1985. 1985 Annual review of project performance results. Independent Evaluation Group (IEG), The World Bank Group.

142 *Typology of Irrigation Systems in Ghana*. Regassa E. Namara, Leah Horowitz, Shashidhara Kolavalli, Gordana Kranjac-Berisavljevic, Busia Nambu Dawuni, Boubacar Barry and Mark Giordano. 2010.

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Related Publications

Adeoti, A.; Barry, B.; Namara, R.; Kamara, A.; Titiati, A. 2007. ***Treadle pump irrigation and poverty in Ghana***. Colombo, Sri Lanka: International Water Management Institute (IWMI). 24p. (IWMI Research Report 117)

www.iwmi.org/Publications/IWMI_Research_Reports/PDF/Pub117/RR117.PDF

Barry, B.; Kortatsi, B.; Forkuor, G.; Gumma, M. K.; Namara, R.; Rebelo, L-M.; van den Berg, J.; Laube, W. 2010. ***Shallow groundwater in the Atankwidi Catchment of the White Volta Basin: Current status and future sustainability***. Colombo, Sri Lanka: International Water Management Institute (IWMI). 30p. (IWMI Research Report 139)

www.iwmi.org/Publications/IWMI_Research_Reports/PDF/PUB139/RR139.pdf

IWMI (International Water Management Institute). 2007. ***Recognizing informal irrigation in urban and peri-urban West Africa***. Colombo, Sri Lanka: International Water Management Institute (IWMI). 6p. (IWMI Water Policy Briefing 026)

www.iwmi.org/Publications/Water_Policy_Briefs/PDF/WPB26.pdf

Sally, H.; Abernethy, C. L. (Eds.) 2002. ***Private irrigation in sub-Saharan Africa: Regional seminar on private sector participation and irrigation expansion in sub-Saharan Africa, Accra, Ghana, 22-26 October 2001***. Colombo, Sri Lanka: IWMI; FAO; ACP-EU Technical Centre for Agricultural and Rural Cooperation. 328p. + CD.

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International
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ISSN 2012-5763
ISBN 978-92-9090-739-8