KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY,

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POTENTIAL FOR INCREASING AGRICULTURAL WATER PRODUCTIVITY IN THE BLACK VOLTA BASIN, GHANA

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Certification

I hereby declare that this submission is my own work towards the Master of Science (MSc.) and that, to the best of my knowledge, it contains no material previously published by another person nor material which has been accepted for the award of any other degree of the university, except where due acknowledgement has been made in the text.

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Prof. Samuel Nii Odai ....

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(Head of Department) Signature Date

Dedication

I dedicate this thesis to my loving parents, Mr. & Mrs. J. M. Quandzie, my sister Rosemond and brothers John and Anthony and my lovely Rita for their understanding, immense support and sacrifice throughout the period of my study.

Abstract

The effect of over or under irrigation on vegetables is the reduction in yield. The study carried out in the Black Volta Basin that falls within the administrative boundaries of the Upper West region of Ghana, sought to ascertain the potential for increasing agricultural water productivity under various agricultural water management interventions being used for dry season gardening and livestock rearing. Seven sites were selected for detailed studies. Primary and secondary data were collected through desk studies, key informant interviews, questionnaire administration, focus group discussions, field observation and measurements. Statistical and scientific tools such as Microsoft Excel and CROPWAT 8.0 model were used in processing, generating, and analyzing the raw data obtained. The results revealed that agricultural water management intervention in which supply and application of water is under gravity and capillary action gave crop water consumption factors of about 87% each for both tomato and pepper, hence, over irrigation as compared to FAO values for semi-arid to arid conditions under optimal performance should be zero. The riverine intervention using water pumps, pipes, and hoses gave crop water consumption factor of about -8%, thus a water deficit being experienced by pepper. Shallow wells with line and bucket intervention gave crop water consumption factors of about 6% and 24% for tomato and pepper respectively. The intervention in which water pumps are used in lifting water directly from small reservoirs gave crop water consumption factors of about -10% and -25% for tomato and pepper respectively. The intervention that used water pumps to lift water from main canals of small reservoirs to the fields gave crop water consumption factors of between 36% to 16% for tomato and 9% to -25% for pepper.

The physical and economic productivities from the results are generally low as compared to the FAO standards for arid and semi-arid conditions. The agricultural land productivity was also very low in the study area. But livestock water productivity was high although the animals were not engaged in any dry season agricultural activities.

Hence, the study concludes that the potential to increase agricultural water productivity exists for all the interventions considered with the highest in gravity and capillary action based systems. This is possible if water resources engineers and managers with in-depth knowledge in agriculture water management are engaged to plan, operate and manage such projects.

Keywords: Black Volta Basin, Crop**,** Dry season, Intervention, Livestock, Water productivity

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Abbreviations used in text

AEA	Agricultural Extension Agents
ALP	Agricultural Land Productivity
AWM	Agricultural Water Management
BVB	Black Volta Basin
BVR	Black Volta River
CPWF VI	Challenge Programme on Water and Food Volta One
CWCF	Crop Water Consumption Factor
CWR	Crop Water Requirement
EWP	Economic Water Productivity
FAO	Food and Agriculture Organisation
FGD	Focus Group Discussion
GIDA	Ghana Irrigation Development Authority
GPS	Global Positioning System
GSS	Ghana Statistical Service
LWP	Livestock Water Productivity
MDG	Millennium Development Goal
MoFA	Ministry of Food and Agriculture
MWRWH	Ministry of Water Resources, Works and Housing
NIR	Net Irrigation Requirement
PCWP	Physical Crop Water Productivity
SFP	Single Factor Productivity
SW	Shallow Well
SR	Small Reservoir
USDA	United States Department of Agriculture
USEPA	United States Environmental Protection Agency

UWR	Upper West Region
WUA	Water Users Association

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INTRODUCTION

1.1 Background

The Volta basin is the 9th largest in sub-Saharan Africa (GEF-UNEP, 2002) and it is estimated to drain an area of about 400,000km² (Rodgers *et al*., 2007) into the Gulf of Guinea. The socio economic benefit derived from the natural resources provided by the Volta Lake is also worth noting. This basin makes up almost 28% of the total West Coast (FAO, 1997) and is shared by six riparian countries, of which Burkina Faso (46%) and Ghana (39%) share the major portion, while the remaining 15% is shared by Togo (6%), Benin (4%), Mali (3%), and Cote d'Ivoire (2%) (Barry *et al*. 2005). The main Volta basin is made up of four major sub-basins which are the Black Volta, White Volta, Oti, and the Lower Volta sub-basins. The fresh water resources that contribute water to the Volta Lake originate from the tributaries that fall within the Volta basin. The estimated annual precipitation ranges from 1500mm per year in the south to about 400mm per year in the upper regions of the basin (FAO, 2001). Potential evaporation rates are high, ranging from 1,500mm in the south to more than 2,500mm in the north and less than 10% of the precipitation becomes useable as river flow (GLOWA-Volta, n.d.). This ultimately contributes to the somewhat perennial drought in the upper regions within the basin.

The Black Volta sub-basin in the Volta basin is the study area for this research work, but will be referred to as the Black Volta basin (BVB) in the following write up. The BVB is sub-divided into sub-catchments and these are the Nwokuy, Dapola, Bamboi, Noumbiel and Lerinord sub-catchments (Kirby *et al*. 2010). The BVB drains an area of about 149,015km² and receives an annual rainfall between 1023.3mm - 1348.0mm. The mean annual flow of the Black Volta River at Bamboi measuring station is estimated to be about 200m³/s, out of which about 42.6% originate from outside Ghana (GEF-UNEP, 2002). This is an indication that a larger portion of the precipitation and its eventual runoff in the Black Volta River occurs in

Ghana, hence, the country as a whole and the Upper West Region in particular could maximize its benefit derived from the water resources available. In order to realize the full potential of the water resources in the BVB and in particular the portion in Ghana, the study seeks to concentrate on the Dapola, Noumbiel and Vonkoro sub-catchments which fall within the Upper West Region of Ghana. It cannot be said that the people in the Upper West Region are not benefitting from the water resources but the magnitude and impact that it is having on their lives is what must be looked at with the view of increasing it. There have been many social interventions in the region which have produced marginal benefits in the agricultural sector and economic well-being of the inhabitants. Thus with all these interventions, the region according to the Ghana living standard survey (2008) is one of the poorest in the country. Hence, in order to better improve the livelihood of the inhabitants with particular reference to the local farmers and livestock owners, the option of providing solutions based on engineering research should be the way forward.

The very crucial resource being considered has the Dublin principles (ICWE, 1992) clearly spelling out its importance; the declared principles that states that fresh water is a finite and vulnerable resource essential to sustaining life and that its management should be based on participatory approach involving users, planners, and policymakers at all levels with particular focus on women and that its economic value among competing uses should be recognised. Thus agricultural water use should be managed with this in mind. Therefore, the productivity of it should be such that maximum benefit is realised at all times and its conservation promoted.

This thesis aims at how best the potential of agricultural water productivity can be increased while assessing how the productivity of agricultural land in the Upper West Region of Ghana which falls within the Black Volta basin can also be enhanced.

1.2 Problem Statement

In most African and Asian countries especially sub-Saharan countries, the growth rate of the population outstrips gains made in agriculture productivity hence, exacerbating the already existing food insecure situation. Food insecurity exists when people lack access to sufficient amounts of safe and nutritious food and therefore not consuming enough for an active and healthy life. This may be due to the unavailability of food, inadequate purchasing power, or inappropriate utilization at household level (FAO, 2002). It is known that food insecurity is progressive and occurs over a set of conditions from food secured situations to full scale famine. It can be classified as either chronic or transitory. Chronic food insecurity translates into a high degree of vulnerability to famine and hunger which mainly exist in poor developing countries.

Worldwide, around 852 million people are chronically hungry due to extreme poverty, while up to 2 billion people lack food security intermittently due to varying degrees of poverty (FAO, 2003). In Sub Saharan Africa, it is estimated that about 62% (IFAD and FAO, 2008) of the population live in rural areas, are poor and engage in subsistence farming as their means of livelihood.

The linkage between the rural communities, poverty alleviation, hunger reduction and rising income levels through agricultural productivity cannot be overlooked in developing countries worldwide. Increased agricultural productivity enable farmers to grow more food which translates into better diets and under market conditions, that offers a level playing field resulting in higher farm incomes. With more money, farmers are more likely to diversify production and grow higher-value crops, benefiting not only themselves, but creating a rippling effect thus affecting the regional, continental and worldwide economy as a whole (IFPRI, 2004).

1.3 Justification

The Black Volta basin falls within the Upper West, Northern and Brong Ahafo regions of Ghana. Poverty levels in these regions are high with particular reference to the Northern and Upper regions, which is an undeniable fact. This has led to the migration of the youth to the south of the country to seek greener pastures which are non-existent. Unreliable rainfall pattern and harsh climatic conditions in the basin have also affected the interest of the young and educated indigenes in engaging in agricultural production in the basin. Considering that the level of agricultural production has a direct link to income level, it presupposes that most of the people engaged in this sector are poor with an accompanying low purchasing power. Undertaking this study will seek to provide key findings on the avenues, processes and systems needed in the basin to increase the potential of agricultural water productivity.

This research will also contribute immensely to achieving the targets set for Millennium Development Goal (MDG) One (1) target One (1) which seeks to eradicate extreme poverty and hunger by 2015 and target One (1) Goal Seven (7) which also seeks to ensure environmental sustainability. More specifically, these targets aim at integrating the principles of sustainable development into country policies and programmes and reverse the loss of environmental resources (UN, 2011). Policy formulation in the future can be based on this study in view of the fact that it is to assess the potential for increasing agricultural water productivity in an environmentally sustainable way.

1.4 Objectives

The overall objective of this research is to assess the potential for increasing agricultural water productivity for the dry season agricultural activities in the Black Volta basin, Ghana.

The specific objectives of the research are to:

a) Estimate crop water consumption factor for some selected crops within the Black Volta basin, Ghana.
b) Quantify agricultural water productivity of selected crops and livestock in the Black Volta basin, Ghana.
c) Assess agricultural land productivity in the Black Volta basin, Ghana.

2.0 LITERATURE REVIEW

2.1 Introduction

This chapter focuses on the types and definitions of some Agricultural Water Management interventions as shown in Table 2.1; productivity in general terms, (crop and livestock) water productivity, land productivity, and water use efficiency.

Table 2.1: Some AWM Interventions

AWM intervention	Field Water Delivery Mechanism
Small Reservoirs/Dams/Dug Outs	Canals, Laterals, Furrows
	Bucket and line (rope)
River/stream	Diversions, Laterals, Furrows
	Bucket and line (rope)
Shallow Wells	Laterals, Furrows
	Bucket and line (rope)
Water Pumps	Laterals, Furrows
	Pipes and Hoses

2.2 Definitions

2.2.1 Small Reservoir

Small reservoirs can be generally defined as an engineered storage structure used in the impoundment of runoff generated as a result of excess precipitation. However, various world organisations and countries have defined small reservoirs mostly in terms of maximum height of the dam wall and/or storage capacity of the reservoir (Table 2.2). The World Commission on Reservoirs defines small reservoirs as a structure that has a height less than fifteen metres (15m) and a storage capacity that ranges from fifty thousand to one million cubic metres (50,000 to $1x10^6$ m^3).

Table 2.2: Some Definitions of Small Reservoir

Organization/County	Height (m)	Capacity (m^3)
World Bank[1]	≤ 15	
World Commission on Reservoirs[1]	≤ 15	50000 – $1x10^6$
United State of America (USA)[1]	≤ 6	$0.123x10^6$
Government of Zimbabwe[2]	≤ 8	≤ $1x10^6$

Sources: [1]Senzanje and Chimbari (2002), [2]Mamba (2007) cited in Houenou 2010

It is also worth noting that from Annor (2007) small reservoir can be defined in terms of surface area coverage; that is water storage system with surface area greater than one hectare but less than a hundred hectares qualifies as a small reservoir. However, the volume of stored water in most small reservoirs varies with time mostly as a function of siltation, evaporation, seepage and availability of rainfall. But due to ineffective monitoring and de-silting, though some staff gauges have been installed in some small reservoirs with irrigation schemes, most of them cannot be relied on to determine the capacity due to the fact that they were not sited correctly. Hence, a definition based on capacity will be either incorrect or misleading. In the study area however, documentation is available for most of the dams thus the height of the dam wall is documented and therefore can be relied upon for classification of the dams. Thus from the identified constraint and the mentioned availability of data on the small reservoirs in the study area, the World Bank definition for small reservoirs will be adopted for this study.

2.2.2 Shallow Well (SW)

These are wells which are dug by hands or drilled with machines and may be lined or unlined. It has a depth range of between 1 – 7m depending on depth of water table. These wells may be dug seasonally or permanently.

2.2.3 River

It is defined as a small/large natural stream of water flowing in an unlined or lined channel to the sea, lake or into another river or reservoir.

2.2.4 Water Pump

A pump can be defined as a device for lifting water from inside a well of lower elevation to the ground surface. According to Asawa (2005), water pumps can be classified as either shallow or deep pumps. It is said to be deep when it is installed within the well casing with its inlet submerged below the pumping level.

2.3 Productivity

The definition of productivity can be given in different contexts depending on the discipline and profession. Generally, it is said to be increase in outputs not traditionally accounted for by growth/increase in production inputs. Three of these definitions will be discussed here; firstly, in the field of economics, then secondly in business organizations and thirdly, as applied in agriculture and water issues. In economics, productivity is defined as the ratio of what is produced to what is required to produce it. Hence in the context of economics, it may be thought of as a measure of production efficiency whereas in business organizations, productivity is viewed as a ratio which measures how well an organization converts input resources (materials, labor and machines) into goods and services. The latter definition on productivity acknowledges that on its own, it is not a measure of how efficient the conversion process is. In all of the above given definitions, productivity can be defined as simply the ratio of output to input. Generally, productivity can be computed in either of two ways: total or partial productivity (Molden, 1997 cited in Cook *et al*., 2006; Yamoah-Antwi, 2009; Adu-Dankwa, 2010; Houenou, 2010).

Partial productivity is generally considered as the simplest type of productivity measure; a single type of key input factor is selected for the productivity ratio. Partial productivity can be expressed in a number of different ways such as value-added productivity, single-factor productivity, unit cost accounting and managerial control system and efficiency ratios. In this study the concept of single-factor productivity (SFP) is adopted.

Total productivity is a productivity measure that incorporates all the inputs required to produce a product or provide a service. The inputs could be grouped into conventional and unconventional categories, for as long as they contribute to the total inputs required to produce an output. From Molden (1997), total productivity is defined as the ratio of total output to the total input and also from Houenou (2010), it is the ratio of total tangible outputs to total tangible inputs. Total input in this study are all tangible inputs used for farming under the particular agricultural water management intervention. These inputs include: water, land, labor, capital, fertilizer, improved seeds and pesticides. Water and land are basic fundamental inputs required for crop production. For good yields (production) [farmers must access capital (funds)] to purchase improved seeds to plant, fertilizer to improve soil fertility, labor to prepare the land and where this activity is beyond the physical strength of farmers, machinery is employed and lastly, pesticides to control pest attacks. If all these inputs are available and appropriately applied, then good yields and high productivity will be achieved. If not, the yields will be poor and productivity low.

2.3.1 Crop Water Productivity (CWP)

From Mahoo *et al.* (2007), the United States Department of Agriculture views water productivity in three ways, and these are: i) Water use (technical) efficiency, which is defined as the mass of agricultural produce per unit of water consumed, ii) Water use (economic) efficiency, which is defined as the value of product(s) produced per unit of water volume consumed, and iii) Water use (hydraulic) efficiency, which is defined as the ratio of volume of water actually used by irrigated agriculture to the volume of water supplied. Various stakeholders in the water sector define productivity differently as shown in Table 2.3.

Table 2.3: Some Definitions of Water Productivity

Stakeholder	**Useful definition**	**Scale**	**Target**
Plant physiologists	Dry matter/transpiration	Plant	Productive utilization of light and water resources
Agronomist	Yield/evapotranspiration	Field	Higher yields (tons/ha)
Larger-scale farmer	Yield/water supply	Field	Higher yields (tons/ha)
Irrigation engineer	Yield/diverted water	Irrigation scheme	Demand management
Water resources planner	$/total depletion	River basin	Optimal allocation of water resources

Source: Bastiaanssen et al. (2003) modified and cited in Mahoo et al. (2007)

Crop water productivity as defined by Molden (1997) is the mass of production or the economic value of production measured against gross inflow, net inflow, depleted water, process depleted water or available water. It can be determined as either the physical crop water productivity (PWP) or the economic crop water productivity (EWP). Thus;

- Physical crop water productivity (PCWP) is computed by dividing the crop yield by the volume of water delivered during the crop's entire growth period.
- Economic crop water productivity (EWP) is calculated by dividing the income realized from sale of the crop yield by the volume of water delivered during the crop's entire growth period.

In this study, crop water productivity will be considered at field (farm) scale. The formula described by Lemoalle (2006), equation (2.1), will be adopted for the computation of the physical crop water productivity, where the denominator will be considered as the volume of water applied or delivered to the crop. For the economic crop water productivity the formula adopted by Faulkner *et al*. (2008), equation (2.2), will be adopted for this study.

$$PCWP = \frac{\text{Crop Yield } [\text{kg}]}{\text{Water Applied } [\text{m}^3]} \qquad [\text{kg/m}^3] \qquad (2.1)$$

$$EWP = \frac{\text{Income obtained from Crop Yield } [\text{GH¢}]}{\text{Water Applied } [\text{m}^3]} \qquad [\text{GH¢/m}^3] \qquad (2.2)$$

2.3.2 Livestock Water Productivity (LWP)

Livestock water productivity in agricultural systems is the ratio of the sum of animal products and services produced to the amount of water depleted in producing them (Peden and Tadasse, 2003).

The sources of livestock water consumption may be, cited as (Zinash *et al.*, 2002):

- Drinking water
- Water contained in producing feeds

Livestock product and services include among others meat, milk, hide, manure, ploughing, and transport. In this study, livestock water productivity (LWP) will be computed using the formula by Peden and Tadasse (2003), equation (2.3), and cited in Houenou (2010).

$$LWP = \frac{\text{Livestock Product } [\text{GH¢}] + \text{Livestock Services } [\text{GH¢}]}{\text{Water Consumed } [\text{m}^3]} \qquad [\text{GH¢/m}^3] \qquad (2.3)$$

2.3.3 Agricultural Land Productivity (ALP)

Agricultural land productivity measures the crop yields (t) or the income generated on sale of produce from the piece of land. Yields obtained from a plot of land also depend on the nutrients in the soil. For higher yields, the appropriated inputs such as fertilizer, improved seeds, pesticides, and labor must be used to improve the conditions under which crops grow. In this study, the sum of individual farmers' crop yields is used in the computation of agricultural land productivity (ALP), as in equation (2.4).

$$ALP = \frac{\text{Crop Yield } [\text{t}]}{\text{Cultivated } [\text{ha}]} \qquad [\text{t/ha}] \qquad (2.4)$$

2.4 Crop Water Consumption Factor

Crop water consumption factor (CWCF) is the ratio between net crop irrigation water requirement (NIR) and the volume of water that reaches the irrigation plots and that is effectively applied to the crops throughout its specified growth period (V_{app}) (Willardson *et al*., 2002; Clemmens and Burt, 1997; Molden, 1997) as indicated in equation (2.5). Crop water consumption factor is also known as water use efficiency (Oweis *et al*., 2003; Kijne *et al*., 2003; cited in Houenou, 2010). Thus:

$$CWCF = \frac{\mathrm{NIR}}{\mathrm{V_{app}}} \tag{2.5}$$

The net crop irrigation requirement (NIR) can be computed using the CROPWAT model. The CROPWAT model is a water balance-based computer programme used to calculate crop water requirement (CWR) and crop irrigation water requirements (NIR) from climate and crop data (FAO, 1992). NIR basically represents the difference between the crop water requirement or the standard evapotranspiration (ET_c) and effective precipitation. Its main purpose is for planning and managing irrigation projects. CROPWAT 8.0, the latest version, under windows interface which was formulated by the FAO in 2009 is used in this study. The CROPWAT model used the equation below to compute NIR.

$$NIR = \mathrm{k_c \times ET_o - P_{eff}} \tag{2.6}$$

Where, NIR = net irrigation requirement [mm/d]; k_c = crop coefficient [dimensionless]; ET_o = potential evapotranspiration [mm/day]; P_{eff} = Effective precipitation [mm/day].

The crop coefficient, k_c is a fraction of the crop type and the period of the growing season. P_{eff} is the fraction of the total precipitation, (P) that is available to the crop and does not run off. If the right hand side of equation (2.6), is greater than zero, i.e. NIR > 0, then for the particular crop, some amount of water would have to be supplied by some irrigation method to make up for the deficit which the effective rain (P_{eff}) was not able to supply. If the right hand side of equation (2.6), is equal to zero, i.e. NIR = 0, then there would be no need to irrigate since the effective rain (P_{eff}) is equal to the standard evapotranspiration (ET_c) of the particular crop through its various growth stages. And in the situation where NIR < 0, it shows that the effective rain was more than the ET_c, and irrigation would not be required. In other words the soil field capacity is likely to be exceeded and runoff or a waterlogged situation may come into existence.

According to Smith (1991), effective rainfall can be calculated using common empirical methods that are based on actual rainfall data. These are:

- Fixed percentage of rainfall

P_{eff} = Fixed percentage *P (2.7)

Where P_{eff} is the effective precipitation; the fixed percentage is to be given by the user to account for the losses due to runoff and deep percolation, with typical values ranging from 0.7 to 0.9; and P is the measured or generated total monthly rainfall.

- Dependable rainfall

FAO developed this empirical formula to estimate dependable rainfall; it may be used for design purposes where 80% of probability of exceedance is required. Calculation is monthly step based.

For $P_{month} \leq$ 70mm; P_{eff} = 0.6 x P – 10(mm) (i.e. for a time step of every Ten-days) (mm/dec)

For P_{month}> 70mm; P_{eff}= 0.8 x P – 24(mm) (i.e. for a daily time step) (mm/day)

The USDA Soil Conservation Service method for the calculation effective rain is indicated below. Calculation is monthly step based.

For P_{month}< 250mm; $P_{eff} = P_{month}$ x (125 – 0.2P_{month}) / 125

For P_{month}> 25mm; P_{eff} = 125 + 0.1 x P_{month}

Where, P_{eff} is effective rainfall and P_{month} is total monthly rainfall (mm/dec).

It must be clearly noted that for this thesis work the worst case scenario of assuming that there was no rains during the plant growing period was adopted, hence, P_{eff} is assumed to be zero. That is the amount of water required by particular crops throughout their growing period is solely supplied by means of irrigation methods.

Potential evapotranspiration, ET_o is calculated using FAO Penman-Monteith equation (Allen *et al*., 1998) below with parameters of temperature, relative humidity, sunshine hours, and wind speed.

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T + 273} U_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34U_2)} \quad (2.8)$$

Where, ET_o is reference evapotranspiration [mmd^{-1}], R_n is the net radiation at the crop surface [$MJm^{-2}d^{-1}$], G is soil heat flux density [$MJm^{-2}d^{-1}$], ($e_s - e_a$) represents the saturation vapour pressure deficit [kPa], U_2 wind speed at 2m height [ms^{-1}], Δ represents the slope of the saturation vapour pressure curve [kPa^oC^{-1}], e_s is saturation vapour pressure [kPa], e_a is actual vapour pressure [kPa], T is mean daily air temperature at 2m height [^oC], γ is psychrometric constant [kPa $^oC^{-1}$].

To compute the net crop irrigation requirement, CROPWAT model requires the data below from the nearest meteorological station and research station or field:

- Crop data – the crop type and planting date.
- Climatic data – mean monthly maximum and minimum temperatures (^oC), monthly rainfall (mm), relative humidity (%), sunshine duration (hours) and wind speed (m/s).
- Information on meteorological station; country, name, altitude, latitude, longitude.

3.0 STUDY AREA DESCRIPTION

3.1 Introduction

The portion of the Black Volta basin (BVB), in which the Upper West Region of Ghana is located is described in this chapter. The Location and Size, Population, Vegetation and Land use, Climate, Relief and Drainage, Soil characteristics, Geological Setting, Hydrogeological Setting, and Socio-economic characteristics are described in this section.

3.2 Location and Size

The BVB is located approximately between latitudes 7.5ºN and 11ºN and covers about 21% of the whole Volta basin (Mote, 1997). It is made up of five sub-catchments namely Lerinord, Nwokuy, Dapola, Noumbiel and Bamboi. The total catchment area of the basin is 149,015km² with about 23.6% of it in Ghana (GEF-UNEP, 2002). The BVR flows through these riparian countries: southern Mali (source), southwestern Burkina Faso, northeastern Ivory Coast and Ghana. These countries contribute portions of their national lands to make up the Black Volta basin. In Ghana, there are thirteen (13) main tributaries with its accompanying catchment areas draining into the BVR (Barry *et al*., 2005).

The Upper West region of Ghana is located at the northwestern corner of Ghana. It has an area covering about 18,8478km² which is approximately 7.7% of the total land area of the country. The region is bordered by Burkina Faso to the north, Ivory Coast to the west, to the east by the Upper East region of Ghana and to the south by the Northern region of Ghana. The capital town of the Upper West Region is Wa municipality.

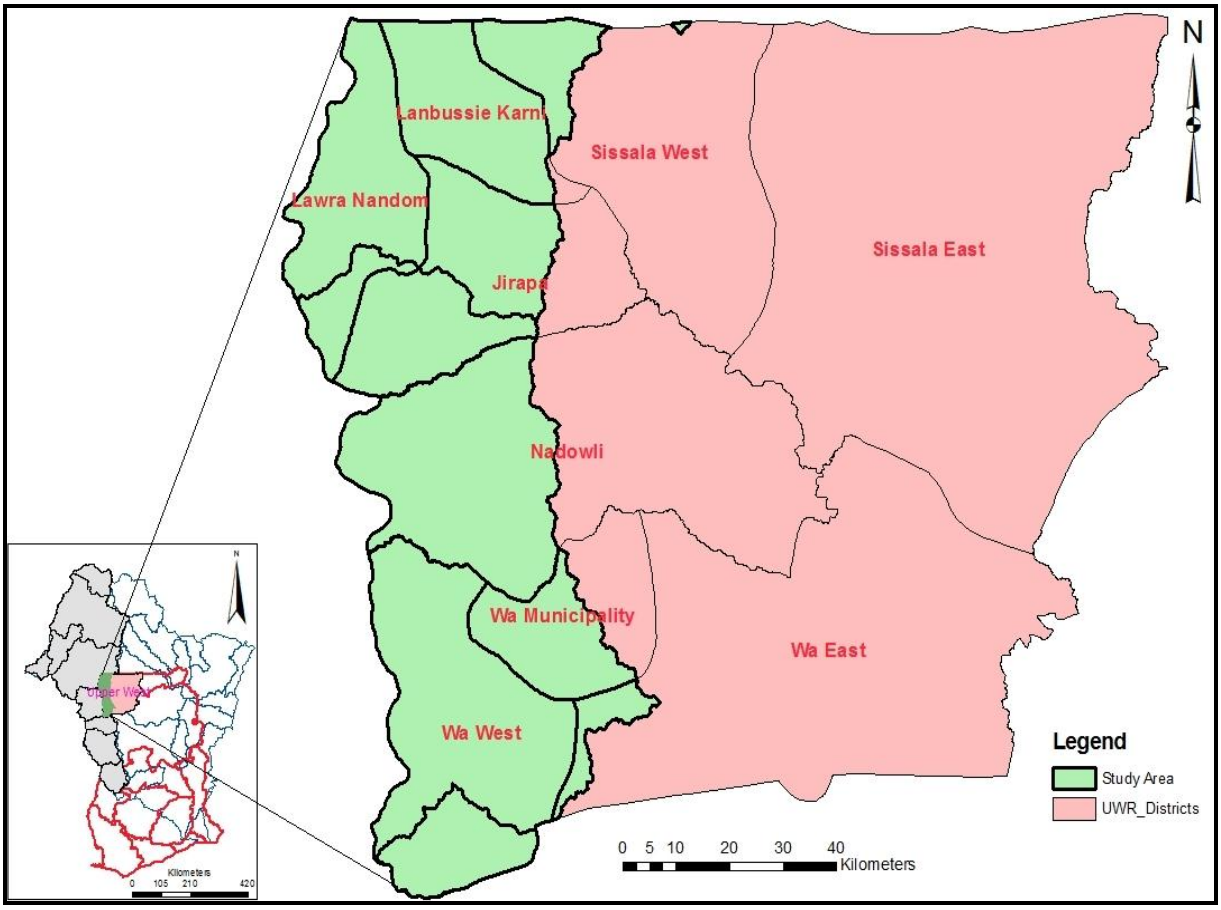

Figure 3.1: Location of Study Area in the Black Volta Basin Catchment in the UWR, Ghana

3.3 Population

Socio-demographic analysis for the BVB in Ghana specifically has not been done, since the basin encompasses wholly or partially some districts in the various regions contributing to the catchment of the BVB. The census done in the country is based on the administrative demarcation of regional lands. But Nabila (1997) in his report made some assumptions and presented Table 3.1 below as general trend of rural and total population in the BVB in Ghana but cautioned the use of the projections and population estimates.

Table 3.1: Estimated Population of the Black Volta Basin in Ghana.

Year	1984	1990	1995	2000	2005	2010	2015	2020
Rural population	446,905 (73.6%)	609,395 (82.5%)	719,151 (82.4%)	851,762 (82.37%)	1,012,565 (82.32%)	1,208,242 (82.28%)	1,447,336 (82.29%)	1,740,537 (82.29%)
Total population	607,372	738,449	872,332	1,034,067	1,230,088	1,468,405	1,758,791	2,115,192

Source: Nabila, 1997 and cited in GWI, 2009.

The year 2010 national census has it that the population of the UWR is about 702,110 which represent approximately 2.8% of the national population. The region has a male population of 314,182 (48.59%) and 360,928 (51.41%) are females. The region is also indicated to have a mean population density of about 37 persons per square kilometre. It is noted that the growth rate for the region is 1.5% (GSS, 2010).

3.4 Vegetation and Land Use

The vegetation of the BVB is that of the typical Guinea savannah according to Chipp (1922) and it's no different from what pertains in the UWR. The vegetation is characterised by short grasses (tussock grasses dominating) and from Agorsah (2003) in GWI (2009) the trees in the BVB are short (< 20m high), thick barks which are fire hardy with the ability to reproduce from dormant buds. Thus, it forms new leaves and some flower just before the beginning of the rains. Some trees with economic value can also be identified in the BVB and these include mango (*Mangifera indica),* shea butter (*Butyrospermum parkii),* Dawadawa (*Adansonia digitata)* and the Baobab. These attributes of the larger BVB can be said to apply to the UWR of Ghana. The majority of the land is rural and its main use is for agricultural production and free range livestock grazing. It is only in the district capitals that some lands are being used for commercial and industrial purposes.

3.5 Climate

Barry *et al*. (2005) indicate that the BVB has the following agro-ecological composition: Sahel, Sudan, Guinea Savannah, Transitional Zone and Moist Semi Deciduous. And from Sultan *et al*. (2005) and Rodgers *et al*. (2007), the uni-modal rainfall experienced in the basin is as a result of the northward and southward movement of the Inter-Tropical Convergence Zone (ITCZ). The rainy season starts gradually from March and peaks in September. But Van de Giesen *et al*. (2001) reported that the basin experiences high degrees of spatial and temporal variability in rainfall. In the BVB, the mean annual rainfall ranges between 1023.3mm and 1348.0mm and the annual potential evapotranspiration varies between 1450.0mm and 1800.0mm, with the annual mean temperature and the relative humidity ranging between 25ºC – 27.8ºC and 59% - 77%, respectively (Barry *et al*., 2005).The outlined conditions according to Owusu *et al*. (2008) make agriculture production unreliable, hence, worsening the food security situation in the basin. This is the exact mirror image of what is happening in the UWR.

3.6 Relief and Drainage

The BVB is characterised by a considerable variations in the relief system. A large portion of the basin in Ghana falls within the Guinea savannah zone which is characterised by gentle undulating slopes from north to south, hence promoting surface flow. Mote (1997) in GWI (2009) has it that the topography of the northern sector ranges between 300mm and 600mm above sea level. From the MWRWH (1998) the mean annual runoff of the Black Volta River (BVR) is 7,673 x 10^6 m^3. The BVR together with its tributaries such as Kamba, Kuno, Bakpong, etc. drain parts of the Upper West Region (UWR).

3.7 Geology and Soil

The BVB in Ghana and specifically the UWR is in the Guinea Savannah zone which according to Barry *et al*. (2005) contains much less organic matter, hence is lower in nutrients. The BVB in Ghana is underlain generally by three main geological formations, namely: the Birimian, Granite and the Voltaian rocks formation and to a minor extent the Tarkwaian system (Barry *et al*., 2005). The UWR is underlain by the upper and lower birimian and associated granite and the granite formation. The soils in these areas mainly consist of savannah ochrosols and groundwater laterites (Andah *et al*., 2003) which give rise to the presences of sandy, sandy loam and laterite. According to FAO (1967), the floodplain soils along the BVR vary from brown sandy clays to silty clays loams. This patchy geology, according to Blench (2006) may well explain why farming systems are so diverse across the UWR.

3.8 Hydrogeological Setting

The geological formation of the BVB has a direct bearing on the groundwater occurrence. The rocks in the basin and the region are essentially impermeable and therefore lack primary porosity (Kortatsi, 1997). Secondary porosity development is responsible for the groundwater occurrence. Kortatsi (1997) has it that there are two main aquifer systems in the basin namely: weathered aquifers and the fissured aquifers.

The weathered zone aquifers usually occur at the base of thick weathered layers which vary between 0 - 100m (Barry *et al*., 2005). According to the MWRWH (1998) and also as cited in Barry *et al*. (2005) the yield of these aquifers rarely exceeds $6m^3/h$.

The fissured aquifers are normally discontinuous and limited in area; their occurrence is in fresh rocks and is generally deeper and high yielding than the weathered zone aquifers. This is because fissured aquifers usually occur below the weathered zone.

3.9 Socio-Economic Activities

The BVB in Ghana and the UWR in particular is noted to be one of the poorest regions where indigenes live on less than a dollar a day, the standard set under the Millennium Development Goals. The inhabitants who are mostly farmers engage themselves in both minor and major season farming and also livestock rearing to generate income for their livelihood and sustenance.

The tourism industry in the region is one of the less tapped potentials; the region is known to have a wide variety of cultural displays such as the Damba and Nandonei Bawa dance. The region is also known to have the hippo sanctuary at Wechiau where tourists can be exposed to viewing and some income generated from that.

Commerce between the region and the neighbouring Burkina Faso cannot be over looked. Thus it’s a location where trading activities between the southwestern Burkina Faso and the northwestern Ghana takes place, thus goods from the southern Ghana are sent to be sold.

4.0 METHODOLOGY

4.1 Introduction

The study adopted the following research methodologies for the selection of Agricultural Water Management interventions, determination of crop water consumption factor, crop and livestock water productivities, and agricultural land productivity. These include collection of data through desk studies, reconnaissance survey, questionnaire administration, interviews with key informants, focus group discussions, field measurement and observation and the use of secondary data.

4.2 Desk Studies

The desk study entailed reviewing a number of official reports, articles, journals and thesis works on Agricultural Water Management interventions in the Black Volta Basin and Upper West region of Ghana in particular. Documents on these interventions were obtained from MoFA and GIDA. Table 4.1 gives some details about the chosen interventions.

Table 4.1: Sites and Interventions Selected for Detailed Study

Intervention Site	District	Intervention Mix	Dist. from Cap. (Wa) (km)	Irri. Area (ha)	Height of Dam Wall/Depth of Shallow Well (m)
Busa	Wa Muni.	SW & SR	10	10	6
Biihe	Wa Muni.	SW	8	1.5	1 – 7
Babile	Lawra	SR	75	3	6
Gbetuore	Jirapa	Riverine	62	18	-
Kunzokala	Jirapa	SR	65	-	6
Siiru	Wa West	SR	14	15	6
Yeliyili	Wa West	SR	20	30	6

SW: Shallow Well, SR: Small Reservoir, Irri: Irrigable Area

Figure 4.1 below shows the geographical location of the respective intervention sites indicated by the blue spots in the Black Volta catchment (light green portion) of the Upper West region of Ghana.

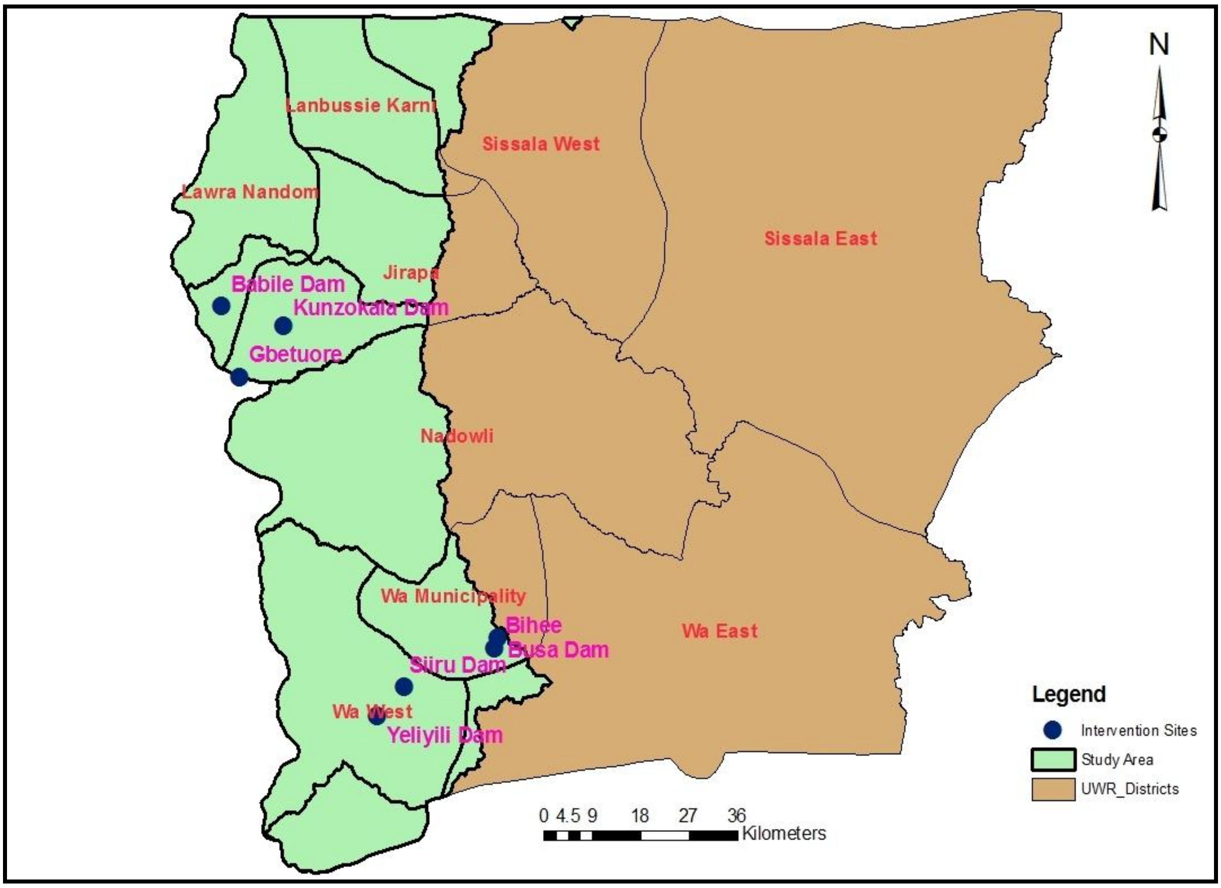

Figure 4.1: Location of Study Interventions

4.3 Criteria for the Selection of AWM Interventions

The selection of these AWM interventions was based on the following criteria; firstly, the technology or intervention should be in extensive use by farmers for dry season gardening. The definition for small reservoirs as indicated earlier in this document was used to select some small reservoirs in the BVB catchment portion of the Upper West region, and also these small reservoirs must have a multiple use character. The next was proximity and accessibility to these selected sites and the availability of some secondary data on these structures and sites. After extensive consultation with key high level officials of MoFA and GIDA, seven of these sites were chosen for detailed study.

4.4 Data Collection

The methods and strategies used in collecting data and vital information for this thesis work is described in detail below.

4.5 Stakeholder Meetings, Interviews and Questionnaire Administration

High level stakeholder meeting was held at which regional directors and some departmental heads of some organisations involved in the agricultural sector attended. Interviews were conducted with key high level stakeholders which included; regional directors and some departmental heads of MoFA and GIDA on the selection of intervention sites, crop and agricultural land productivities. A follow up reconnaissance survey was conducted to the respective sites. At these sites, questionnaires were administered mainly to dry season farmers as indicated in Plate 1 below. This was done with the help and assistance of some AEAs who acted as translators. They assisted the farmers fill out the questionnaire to provide data on the various uses of the small reservoirs, the various crops grown in the dry season, the crops growing period, the crops yields, the irrigation methods used. Data on the various farm planting inputs used and their respective cost were also gathered.

Plate 4.1: Questionnaire Administration to Some Farmers at Gbetuore, Black Volta River Bank

4.5.1 Focus Group Discussion (FGD's) and Observation

After the administration of questionnaire to the randomly selected farmers, the WUA's executives, the leaders of the farmers, some few farmers were brought together to have a FGD to discuss and verify the data gathered through the questionnaire administration at the particular intervention sites. The discussions bordered on issues such as labour charges, irrigation frequency for that site, time and days for irrigating and farm gate prices of crops in the 2011 dry season among others. Observational walks were conducted at the various intervention sites to confirm some of the information gathered through the interviews and FGD's.

4.5.2 Official Records and Secondary Data

MoFA and GIDA provided some official records within which some data was extracted on some of the identified interventions in the study area. The data included some information on the full supply level (FSL), live and dead storages, storage capacity and size of irrigable area of the chosen small reservoirs. The type of crops, some market prices of crops and some intervention introduction dates were also obtained. Productivity standards for the crops were also obtained.

4.5.3 Physical Measurements

The dimensions of some randomly selected farm plots, beds and planting ridges were measured on the field to get first-hand information and also to confirm some of the information received from the WUA executives, MoFA and GIDA officials. Depth of shallow wells dug on the farms was noted. The farm gate weight of locally accepted standard means of selling produce was weighed and noted with its corresponding prices. The geographic locations of the various intervention sites was recorded using a hand held GPS set. At sites where farmers were using bucket and line/rope to draw water from the shallow wells located at vantage points on the farm and/or from the main canal and laterals unto their beds or ridges to water the crops, the volume of water fetched was randomly measured at three different times and the average used in the estimation of the volume of water applied in watering the crops on the field for the entire growing period of the dry season.

Plate 4.2: Measurement of Farmland/Plot at Babile

Plate 4.3: Weight Measurement of Pepper at Busa Farm gate

At sites where the farmers were using motorized pumps to irrigate their farms, the pumping rates (discharge rate) for some of the pumps were determined through using containers that had been calibrated with standard one litre measuring cup to determine their volumes and a stopwatch to measure the time to fill up. The volume of water applied in watering the crops on the field for the entire crop growing period were determined using equation (4.1) below:

$$V_{app} = \text{NID x Du x PR} \qquad [m^3] \qquad (4.1)$$

Where V_{app} = volume of water applied in (m^3) or (cu.m), NID = number of irrigation days for entire dry season (days), Du = duration of irrigation per day (seconds/minutes/hours), PR = pumping rate (m^3/s).

At sites where farmers were using water released from small reservoirs by the opening of valves to allow water to flow through canals and laterals to fill furrows on the fields of farmers for irrigation, the volume of water applied was measured by firstly, taking the dimensions of the main canal and laterals of the particular scheme and recorded. The depth of flow and wetted perimeter were also measured and noted. The water surface velocity was measured using the float method. Five readings were taken and the average found and used in the computation of the surface velocity. This was done using equation (4.2); it is a formula adopted from USEPA (1997) as indicated below:

$$V = 0.8 \times \frac{L}{t} \qquad [m/s] \qquad (4.2)$$

Where L = distance (m) over which the time ‘t’ (s) was recorded and 0.8 is the reduction factor since not all the water flows with the same velocity both at the bottom and at the surface as in the JICA’s technical guidelines for irrigated agriculture (2004) and cited in Adu-Dankwa (2010).

The discharge (Q) of water was computed using equation (4.3) as indicated:

$$Q = V \times A \qquad [m^3/s] \qquad (4.3)$$

Where A = flow area (m^2) and V = average velocity (m/s) of flow as computed using equation (4.2) above.

Note: the stop valve was fully opened to allow maximum flow as it is the normal practise on every irrigation day. And also it must be stated that the scope of the work did not include losses due to seepage and leakages, so were not considered in the computations in this thesis work. Since the study was done at the farm/field level, loss here may not be losses when viewed at the basin scale.

The volume of water applied to the field was found using the relation in equation (4.1) above by replacing the pumping rate (PR) with the discharge rate in equation (4.3). The irrigation duration is the time taken for the furrows on the field to get filled up. At other plots and sites where this was not appropriate, dimensions of furrows were taken and the time it takes for water to fill up was noted and subsequently the volume found per the number of furrows on the field.

4.6 Crop Water Consumption Factor (CWCF)

The crop water consumption factor (CWCF) is the ratio of the net crop irrigation water requirement (NIR) to the volume of water that is effectively applied to the crop on the field for the entire growth period specified (V_{app}). This ratio according to Oweis *et al.* (2003) and Kijne *et al.* (2003) is also known as the crop water use efficiency.

$$CWCF = \frac{\mathrm{NIR}}{\mathrm{V_{app}}} \tag{4.4}$$

The net crop irrigation water requirement (volume of water required by crops throughout its growth period) (NIR) was computed using the FAO CROPWAT 8.0 model, which is based on equation (2.6). This was done by accessing secondary climatic data of the Wa meteorological station from the FAO CLIMWAT 2.0 model. Intervention site specific coordinates (latitude, longitude and altitude) were taken with the GPS hand held set which also served as input data for the CROPWAT 8.0 model. The effective rainfall for this study work was set at zero. This is to take care of a worst case scenario which is normally what happens in the dry season in that part of the country. The crop water consumption factor for the selected crops was computed using the relation in equation (4.4) above for the various specific intervention sites.

4.7 Agricultural Water Productivity Quantification

4.7.1 Crop Water Productivity

The crop water productivity for this thesis work was determined for both physical and economic (monetary) agricultural water productivities.

Physical crop water productivity (PCWP) was computed using equation (4.5) below:

$$PCWP = \frac{\text{Crop Yield}}{\text{Water Applied}\left(\mathrm{V_{app}}\right)} \qquad [\mathrm{kg/m^3}] \tag{4.5}$$

The crop yield (kg) for the dry season of 2011 was gathered through interviews, focus group discussions and physical measurement with digital scale at the farm gate. Gardeners estimated their yields in the locally accepted means such as crates, basins, sacks, and bowls. Some of the farm produce were measured at the farm gate to confirm the weights given by MoFA monitoring and evaluation officers at the various district offices. Also, local agricultural extension agents in these areas gave some information to corroborate what the gardeners had given in terms of yields. The economic (monetary) water productivity was computed based on the following relation:

$$EWP = \frac{\text{Income Obtained from Crop Yeild}(\text{GH¢})}{\text{Water Applied}(V_{app})} \quad [\text{GH¢/m}^3] \qquad (4.6)$$

Income Obtained from the sale of the crop yield (GH¢) was computed as:

Crop Yield (kg) x Price of crop per unit weight (GH¢/kg).

Local economic situation influences the prices of the crops from season to season and the glut of a particular crop also reduces the market price. This also affects the type of vegetables farmers' plant in the subsequent seasons.

The crop water productivity for the selected crops based on the various interventions was then computed. These were then compared with FAO values for same crops grown in semi-arid and arid regions under optimum irrigation water and agricultural management practises to see if there exist the potential to increase the agricultural water productivities. For this study, the assumption made is that all other factors contributing to the production of the crop were at the optimum level and the varying variable is the agricultural water. A common basis for comparison of agricultural water productivity is needed, so the FAO ranges for good yields in (t/ha) for semi-arid and arid regions were converted into physical crop water productivity (PCWP) by dividing the minimum value of the stated range by the net crop water requirement (assuming a 100% crop water consumption factor). Table 4.2 shows the FAO ranges for good yields and physical crop water productivity.

Table 4.2: FAO Good Yield Range and Corresponding Physical Water Productivity

Crops	**FAO yield range (t/ha)**	**PCWP (kg/m³)**
Tomato	45 – 65	5.5
Pepper	15 – 20	2.2
Onion	35 – 45	7.2

4.7.2 Livestock Water Productivity (LWP)

The livestock considered for detailed study after the initial high level interview and consultation were cattle, goat and sheep. Equation (4.7) given by Peden *et al*. (2002) was adopted for the computation of LWP, thus:

$$LWP = \frac{\text{Livestock Product } (\text{GH¢}) + \text{Livestock Services } (\text{GH¢})}{\text{Volume of Water Depleted } (\text{m}^3)} \quad [\text{GH¢/m}^3] \qquad (4.7)$$

The livestock (cattle, sheep and goat) average selling prices for the past dry season were taken as the respective product revenue or income. The income realised from using cattle for other on farm and off farm activities were noted. This information was collected through interviews with livestock owners who are also mostly crop farmers, questionnaire administration, and focus group discussions. The volume of water consumed by the livestock in a day was also gathered through the same means as mentioned above.

The livestock off farm activities income was for the entire season. And the matured age for the selected livestock ranged between 5 – 5.5 and 1 – 1.5 respectively for cattle and sheep/goat. The main focus of the work is on the 2011 dry season and also to create a uniform basis for comparison of productivities (crop and livestock), the average selling price of the matured livestock were divided by its age (months) to obtain the average annual cost. This was further reduced to five months, thus representing the dry season. Secondary data on estimated water consumption by livestock per day per head was obtained from the “Water For Animals” (FAO, 1986) which gave estimates for voluntary water intake of livestock under Sahelian conditions as 27 L/day/head for cattle and 5 L/head/day for sheep/goat. Also, according to estimates made in 2000 by ONEA (National Board of Water and Sanitation) in Burkina Faso and cited in Houenou (2010), water consumption for cattle per day per head is 39.2 L/day/head and that for sheep/goat is 4.3 L/day/head. Table 4.3 shows the computation of livestock water productivity.

Note: This study takes into consideration only the amount of water consumed by livestock (drinking water) because the animals normally feed in the wild (free range).

Plate 4.4: Cattle Drinking From a Reservoir at Siiru

4.7.3 Agricultural Land Productivity (ALP)

The agricultural land productivity is also a productivity indicator used in assessing agricultural farming systems or interventions. This is done by noting the crop yield in tonnes and the land size on which the yield was realised. The land size that is allocated to or plot size in the irrigable area were measured and recorded. This was done in two ways; measuring tape was used in areas where the boundaries of the farmland were accessible. And in areas where there were difficulty accessing farmland boundaries, the ridges or bed sizes were measured and the total number noted and also the furrow sizes measured and the total number on the farmland noted. These were finally added to arrive at an approximate farmland size. The agricultural land productivity was then computed using equation (4.8) below:

$$ALP = \frac{\text{Crop Yield } (\text{t})}{\text{Cultivated Area } (\text{ha})} \quad \text{[t/ha]} \qquad (4.8)$$

5.0 RESULTS AND DISCUSSIONS

5.1 Identification and Selection of AWM Interventions

The agricultural water management interventions being used in the Black Volta Basin portion of the Upper West region of Ghana were identified through desk studies, key informant interviews and high level stakeholder meeting organised for key organizations and governmental departments involved in the agricultural sector, after a reconnaissance survey and observational assessment was conducted at the intervention sites to acquire first-hand information. This process finally resulted in the selection of seven intervention sites and three crops for detailed studies. Table 5.1 below gives location, type of irrigation scheme, water abstraction method, and water delivery and application mechanisms. Table 5.2 below gives intervention sites and the major crops grown there.

Table 5. 1: Agricultural Water Management Interventions (AWMI)

		Agricultural Water Management Intervention		
Location	**Metro/District**	**Irrigation Scheme**	**Water Abstraction Method**	**Water Delivery and Application Mechanisms**
Busa	WA West	Small Reservoir	Intake Valve and Bucket & Rope	Buckets, Main Canal, Laterals
Bihee	WA West	Shallow Wells	Rope and Bucket	Buckets and Calabash
Siiru	WA Metro.	Small Reservoir	Intake Valve and Motorized Pumps	Main Canal, Hoses, Pipes , Furrows
Yeliyili	WA Metro.	Small Reservoir	Intake Valve	Main Canal, Laterals, Furrows
Kunzokala	Jirapa	Small Reservoir	Motorized Pumps and Bucket	Hoses, Pipes, Furrows, Buckets
Gbetuore	Jirapa	Riverine Water	Motorized Pumps	Hoses, Pipes , Furrows
Babile	Lawra	Small Reservoir	Intake Valve	Main Canal, Laterals, Furrows

Table 5. 2: Indication of Crops and Related Intervention sites

Intervention Sites \ Crops	Tomato	Onion	Pepper
Busa	+	-	+
Bihee	+	-	+
Siiru	+	+	+
Yeliyili	+	-	+
Kunzokala	+	-	+
Gbetuore	-	-	+
Babile	+	+	+

+ Crop grown

- Crop not grown

5.2 Crop Water Consumption Factor (CWCF) (%)

The CWCF gives indication of how the volume of water applied to the crops on the field based on the various interventions are performing. The FAO optimum level is set at 100%, so to give indication as to over irrigation or under irrigation, the CWCF field values were computed using equation (4.4) and the obtained values subtracted from the FAO standard to indicate actual levels of water deficit or over irrigation. Thus, from the CROPWAT model, the net irrigation requirement (NIR) for the crops taken into consideration, the specific locations for the various sites, specific values of the NIR for the crops were generated. So for the crops requiring the specific NIR and assuming that the same volume was applied on the field, then the CWCF for the FAO standard become zero, i.e. CWCF (Theoretical CROPWAT) – CWCF (Volume applied on field) gives indication of over irrigation or deficit water needed to be supplied. Hence for FAO standards, the value will be zero and will be the reference point.

The CWCF for all the crops under the various AWM interventions for the 2011 dry season study shows that the AWM interventions in which the water delivery and application mechanism are under gravitational flow and capillary rise of water tend to have a lot of water wastage. Thus for Babile and Yeliyili, the amount of water delivered to tomato and pepper are about 74% - 87% more than it requires as indicated in Fig. 5.1 and 5.2 below. Thus with this intervention, water stress is not a problem hence, it's an indication that the agricultural water productivity can be greatly increased under this intervention. This can be achieved by giving the WUA executives training on good water management practises needed on such AWM intervention sites and farmers also trained on the required and needed agronomic practises which are prudent for such crops under this intervention.

The AWM interventions under which the delivery and application of water to the crops on the field are undertaken with a line/rope, bucket and calabash are prevalent at the Busa and Bihee sites. It can be seen from Fig. 5.1 and 5.2 below that under this intervention, there is quite a good water volume applied. Although pepper at Busa site experienced water deficit of about 25.4% compared to the FAO standard, this needs to be supplied to prevent water stress, since once a crop undergoes water stress its yield is affected and reduced. This intervention gives the farmers the free hand to apply water to the crops whenever necessary. So they should be trained on the right agronomic practises to use with this intervention. This intervention has a lot of drudgery associated with it but this can be reduced by the use of the right type of treadle pumps which will re-channel the farmer's energy into increasing the crop water productivity at the sites.

The intervention which makes use of motorized pumps, hoses, pipes and furrows as abstraction, delivery, and application mechanisms are used at two sites namely Siiru and Kunzokala. The intervention at Siiru has an earth lined main canal from which motorized pumps are used to abstract water onto the field for application. This system at Siiru has proven from the Fig. 5.1, 5.2 and 5.3 below to be applying quite a good amount of water but for tomato, it can be seen that some amount of over irrigation is occurring. At the Kunzokala site, it was observed that there was no intake valve hence, no canal leading to the irrigable area. Thus farmers mount and pump water through pipes and hoses to far distances to apply to the crops on the field, thus increasing the water losses through leakages along the pipes and hoses. This can partly be the reason for the site experiencing water deficit for both tomato and pepper. It was also observed that the irrigable area was gravelly in nature. The farmers at the site were actively practising mulching and the use of manure on their farms. Thus at this site the provision of an intake valve and a main canal will help reduce the water deficit being experienced.

The riverine water intervention being practised along the BVR at Gbetuore has proven from Fig. 5.2, that the water deficit of about 8.17% being experienced can easily be supplied so that the optimum FAO valve for pepper can be obtained for maximum productivity of the river water being pumped. At this site, it was observed that farmers were farming close to the river banks with no buffer in place to protect the river and nature. The figures below are the CWCF for the various agricultural water management interventions with respect to the indicated crop.

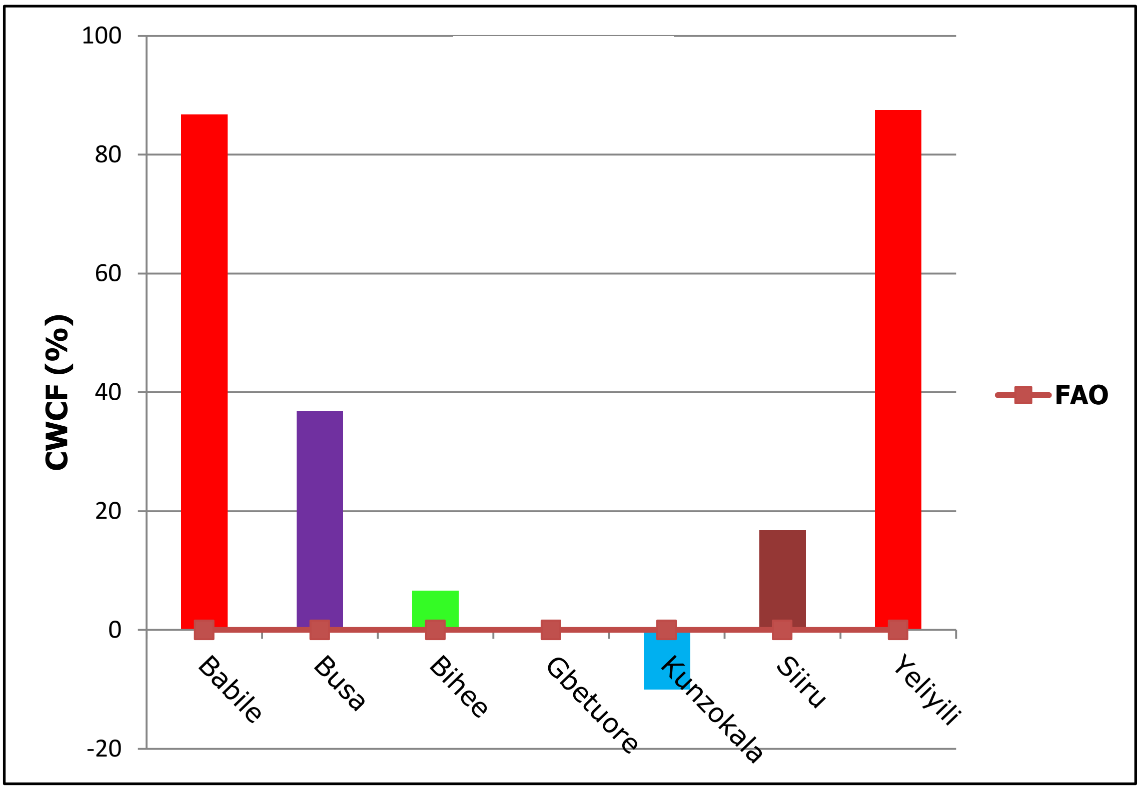

Figure 5. 1: CWCF for Tomato under Indicated AWMI in the BVB Catchment of UWR, Ghana

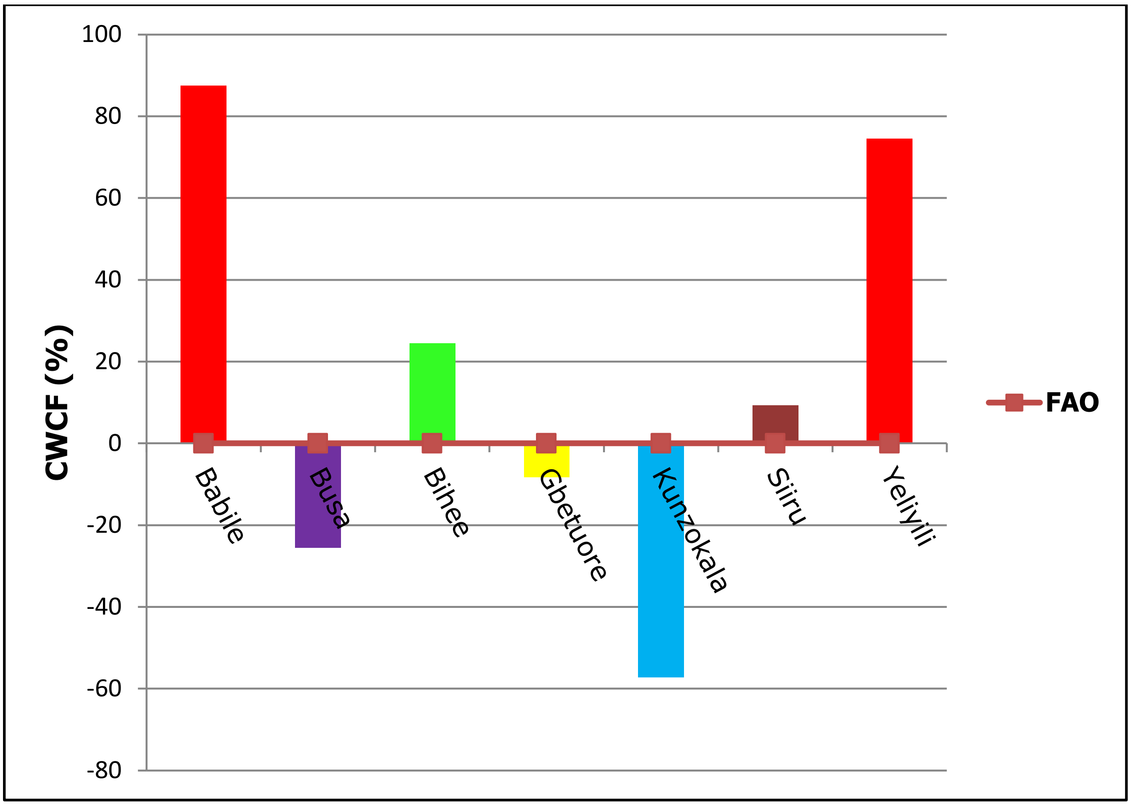

Figure 5. 2: CWCF for Pepper under Indicated AWMI in the BVB Catchment of UWR, Ghana

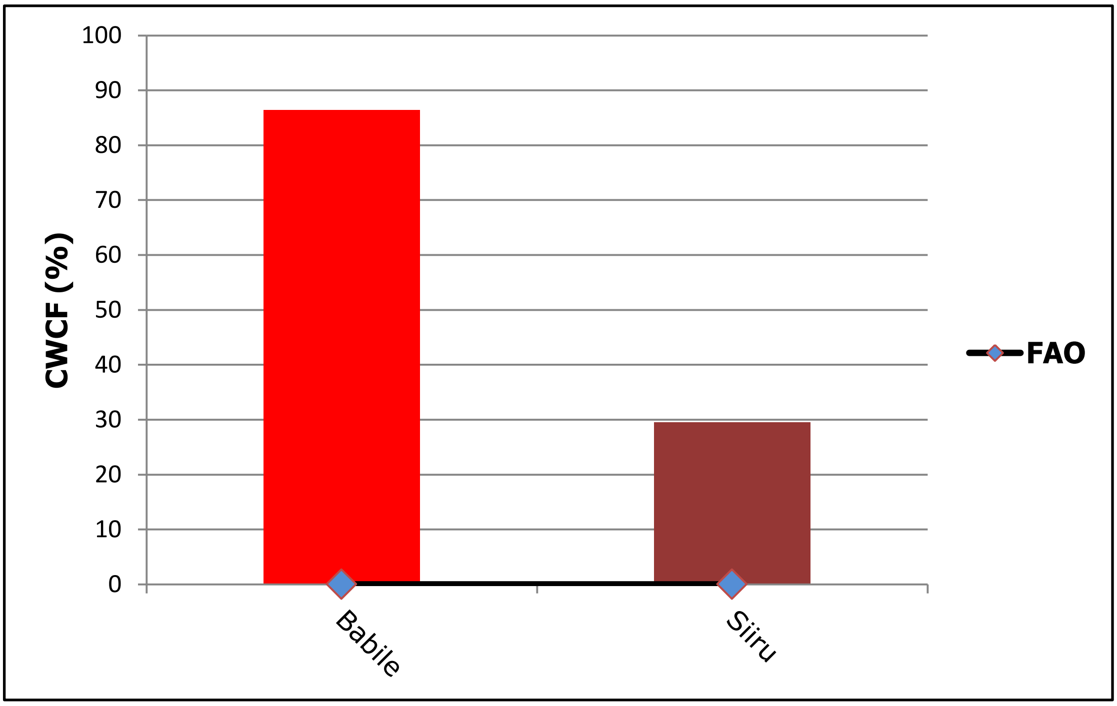

Figure 5. 3: CWCF for Onion under Indicated AWMI in the BVB Catchment of UWR, Ghana

5.3 Crop Water Productivities

5.3.1 Physical Crop Water Productivity (kg/m³)

From Table 5.3 below, it can be seen that the PCWP values differ from site to site with respect to the various interventions and crops. It is also clear that the obtained field values are very low as compared to the FAO standard values for semi-arid to arid areas. But the PCWP values with respect to the identified AWM intervention showed that the farmers in Busa and Bihee obtained higher values for tomato. Thus, these farmers using the shallow wells and buckets are making quite productive use of the available agricultural water.

Table 5. 3: Physical Crop Water Productivity (kg/m³) for the Selected AWMI

Intervention Sites	Tomato	Pepper	Onion
Babile	0.23	0.1	0.11
Busa	1.36	0.19	-
Bihee	1.7	0.12	-
Gbetuore	-	0.23	-
Kunzokala	0.88	0.38	-
Siiru	0.62	0.17	0.19
Yeliyili	0.15	0.11	-
Average PCWP	0.83	0.19	0.15
FAO based physical crop water productivity with CWCF = 100%	**5.5**	**2.2**	**7.2**

The worst performing intervention was at Babile and Yeliyili sites for the crops studied. Here the delivery of water to the field is by gravitational force. The present operational system in place is making a lot of water go to waste in terms of crop production. The farmers and the WUA executives should be trained properly and monitored on the use and amount of water required and delivered to the field for the various crops. Also the furrow dimensions which is appropriate and the planting technology needed to be used for the specific soil type in the area must be made known to the farmers. Thus under this system, greater improvement can be made in the agricultural water productivity and crop productivity increased in proportional terms.

The PCWP of interventions that involves the use of motorized pumps can also do better for the crops studied. The planting/cropping system to be used with this intervention with respect to the different crops can be made available to the farmers by either the irrigation agronomist or the agricultural extension agent whose territory these interventions are present, in order to attain the optimum FAO standards for all the crops. This intervention also allows the farmers the free will to decide when exactly to irrigate the fields and for how long.

It must however be noted that the PCWP at all the intervention sites will be affected in one way or another by other factors such as soil type and corresponding soil nutrients, disease and pest attack and also soil and moisture conservation practices. Improved seeds and general farm maintenance such as weeds control also counts.

5.3.2 Economic Water Productivity (EWP)

The EWP is income realised from the sale of the crop yield divided by the amount of water measured on the field for irrigation through the entire growth period of each particular crop. As expressed in equation (4.6), the following values in Table 5.4 were obtained. Table 5.4 below shows the intervention sites, crops and corresponding EWP obtained.

From Table 5.4 below, the values obtained at the various sites are low compared to the FAO standard values. Gravitational flow interventions at Babile and Yeliyil performing below the optimum showed for tomato with shallow wells at Busa and Bihee being quite good. For pepper, the motorized pump intervention at Kunzokala performed better and had quite a high value but was still lower compared to the FAO standards. The values for onion from the two sites Babile and Siiru are still very low.

Table 5. 4: Economic Water Productivity (GH¢/m³) for Selected AWM Interventions

Intervention Sites	Tomato	Pepper	Onion
Babile	0.22	0.24	0.28
Busa	1.3	0.48	-
Bihee	1.65	0.3	-
Gbetuore	-	0.57	-
Kunzokala	0.84	0.94	-
Siiru	0.6	0.43	0.25
Yeliyili	0.14	0.28	-
Average EWP	0.79	0.46	0.27
FAO based economic water productivity with CWCF = 100%	**4.7**	**3.7**	**4.6**

5.4 Physical Crop Water Productivity and Economic Water Productivity

From Fig. 5.4, 5.5, 5.6 and 5.7 below it is observed that a high PCWP value corresponds to a high EWP value at all the intervention sites. The differences in the EWP values show that the local prices of crop produced differ from site to site and depending on the time of the season, the local market prices of some produce are worth more than others. But in general terms a good yield produces a better economic value when the market is right.

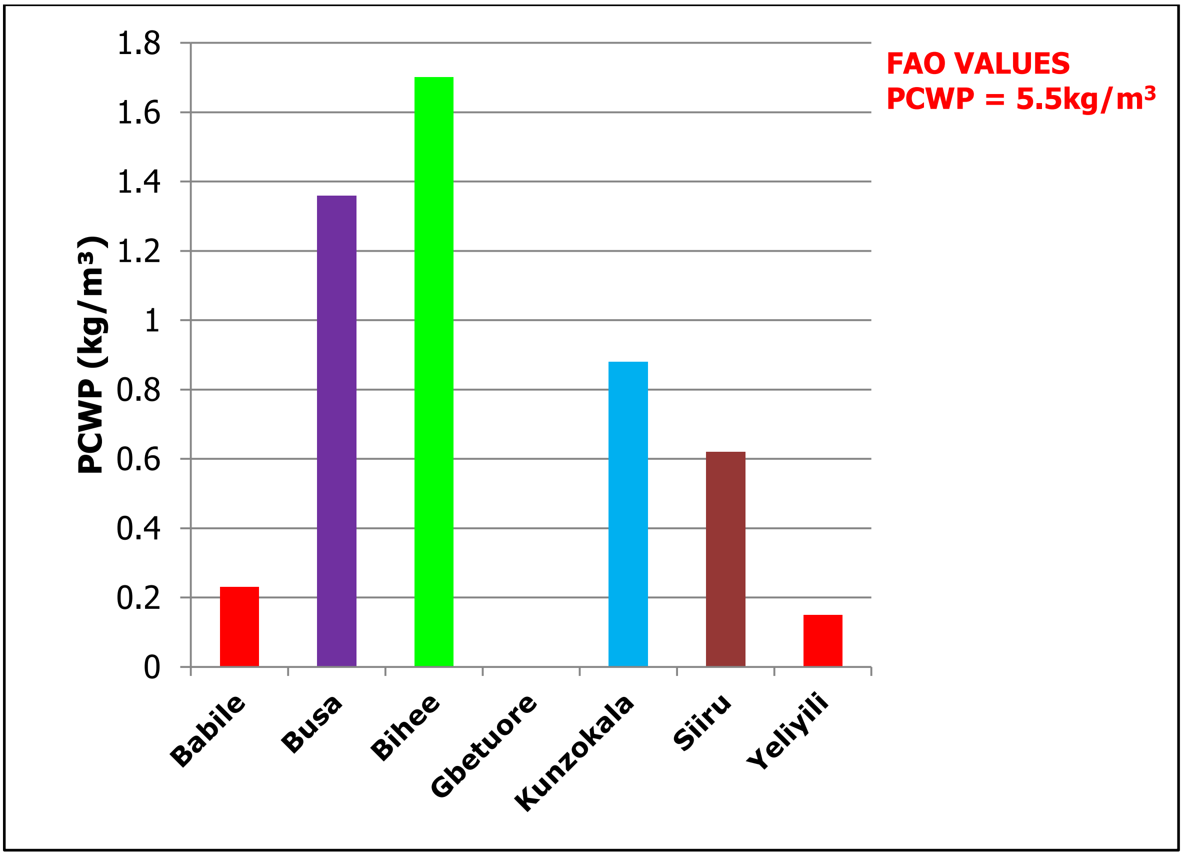

Figure 5. 4: Physical Crop Water Productivity for the Selected AWM Interventions for Tomato

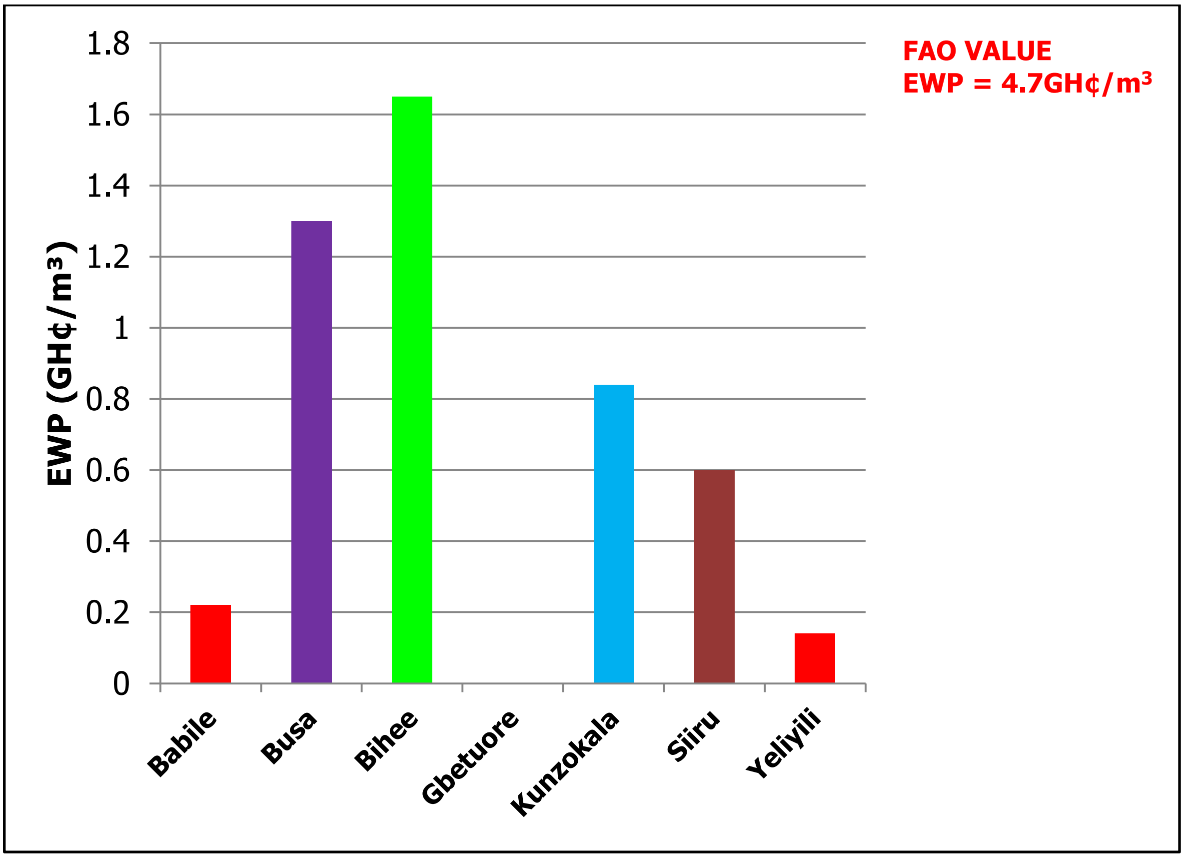

Figure 5. 5: Economic Water Productivity for the Selected AWM Interventions for Tomato

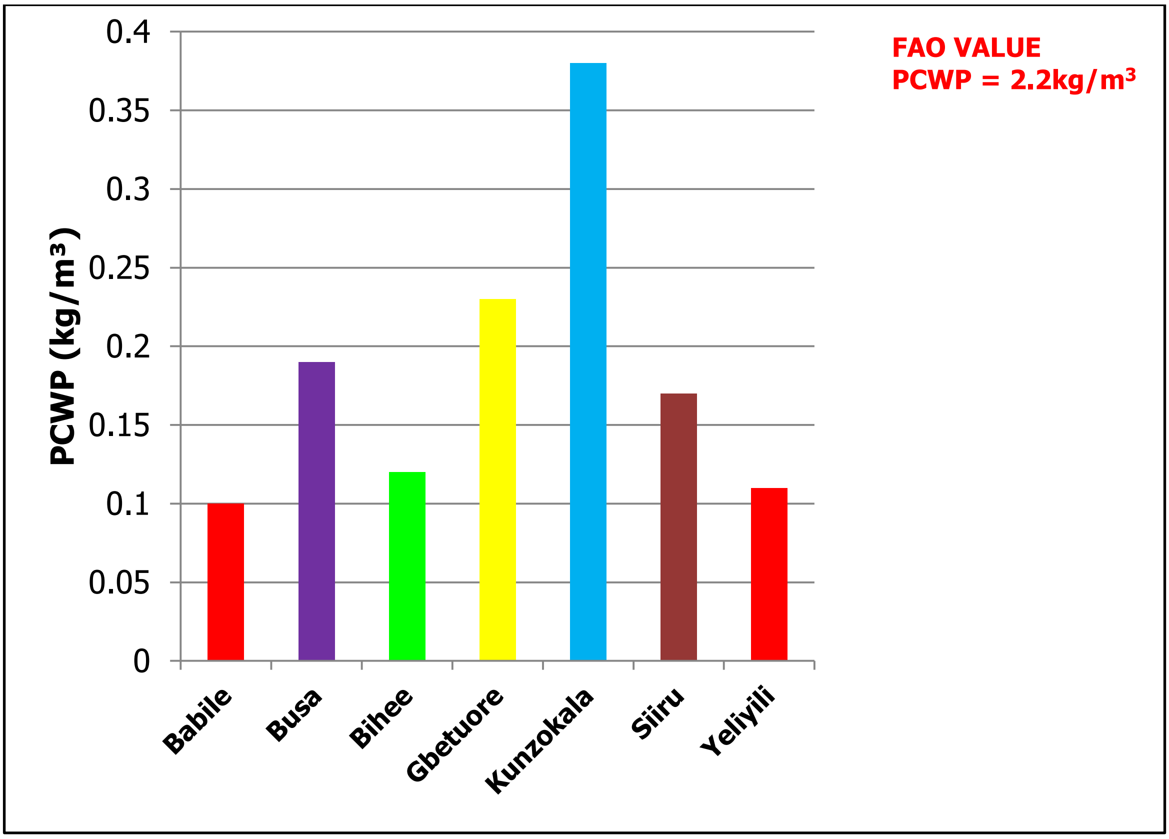

Figure 5.6: Physical Crop Water Productivity for the Selected AWM Interventions for Pepper

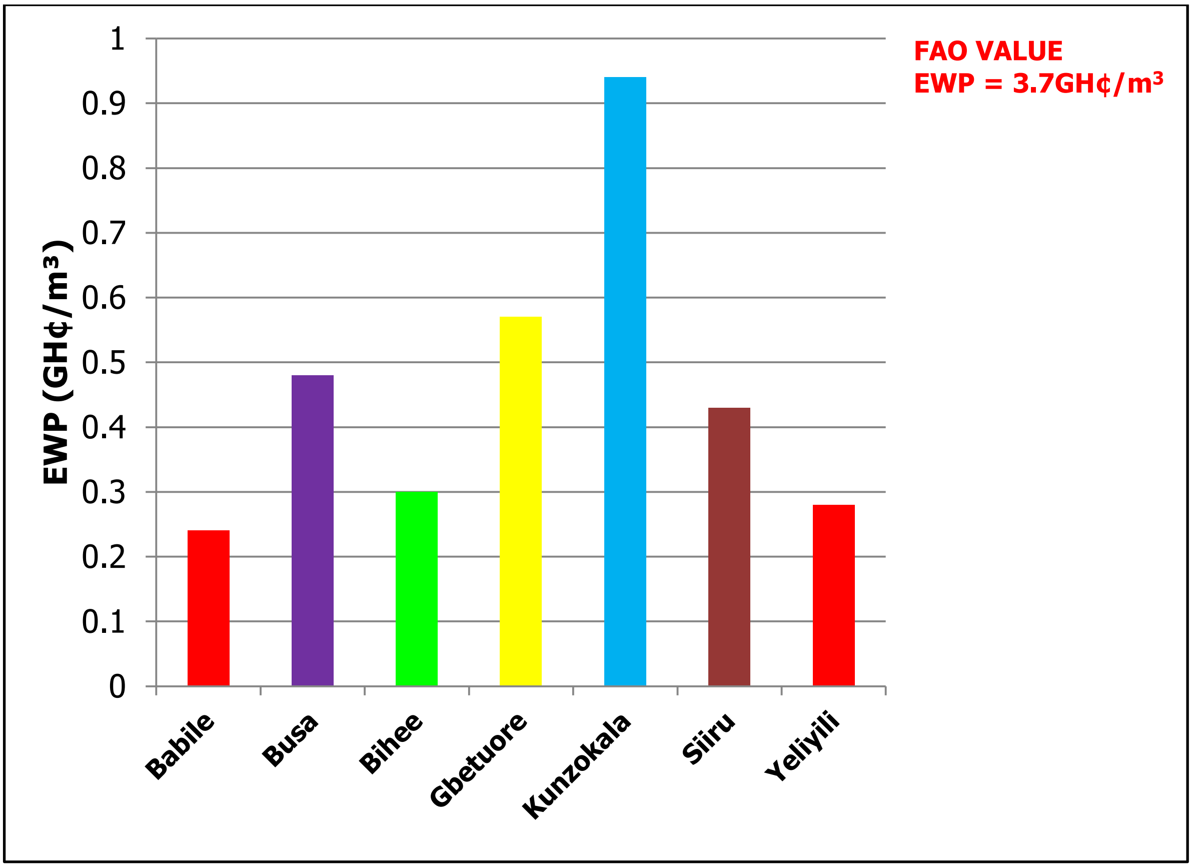

Figure 5.7: Economic Water Productivity for the Selected AWM Interventions for Pepper

5.5 Crop Water Consumption Factor (CWCF) and Physical Crop Water Productivity (PCWP)

The Fig. 5.1, 5.2 and 5.4, 5.6 above a comparison between the CWCF and PCWP for the various intervention sites with reference to the selected crops. It is meant to show the correlation between them or otherwise. In Fig. 5.1 and 5.2, the FAO optimum threshold is one (0) for the CWCF values. Hence values which are way above the optimum of zero are facing heavy over irrigation and values way below it are also suffering from serious water deficit but the closer the value to zero from both sides, the better the volume of water applied. In general the PCWP and CWCF are expected to correlate, thus a low CWCF is expected to give rise to a corresponding high PCWP. Busa, Gbetuore and Kunzokala sites are manifesting this correlation.

From literature (FAO, 2010), tomato, pepper, and onion are said to be very sensitive to both over-irrigation and under-irrigation. In both instances, the yields of these crops are affected hence the optimum PCWP level will not be achieved.

FAO (2010) suggests it that tomato is sensitive to variations in temperature, humidity, sunshine and wind speed. Thus high humidity increases pest and disease attack and fruit rotting. High humidity, strong winds and low sunshine leads to excessive vegetative growth, poor fruit production which culminates into reduced yields. There is also disease attack when waterlogging occurs. Water deficit immediately after transplanting and during flowering and fruit formation causes a reduction in the yield.

According to (FAO, 2010), pepper suffers greater yield losses when there is water deficit just before and during the early flowering stage. This affects yield greatly and waterlogging also causes leaf shedding and poor fruit setting to the plant and also rotting during the fruit ripening stage. Onion is sensitive to soil salinity and over-irrigation and under-irrigation. Water deficit at the fruit formation stage and over-irrigation at all stages leads to the reduction in growth and poor yields.

In Fig. 5.1 above, Kunzokala site shows a water deficit of about 10% of the NIR for tomato as Babile and Yeliyili gave indication of about 87% over-irrigation at both sites. This may be partly contributing to the low PCWP being realised at these sites. For Fig. 5.2, Babile and Yeliyili are over-irrigating pepper as much as about 87% and 74% of the NIR for pepper and that of Busa, Gbetuore, and Kunzokala are experiencing water deficit situation of about 25%, 8%, and 57% respectively. Bihee and Siiru are quite alright but the PCWP across the study area for pepper using all the selected interventions are very low. Since this low trend is showing across interventions, it can be said that other factors might be hindering the realisation of good yields. These can come from the type and nature of seeds being sown across the catchment to lack of soil nutrients and soil types existing or water deficit occurring at the time it should not.

5.6 Livestock Water Productivity

From the questionnaire administered to farmers/livestock owners, key informant interviews, and organised focus group discussions it came out clear that the dominant livestock being reared were cattle, sheep and goats. The cattle mostly were kept for commercial as well as for other social functions. It was made known that depending on the herd of cattle a family or individual owns, the higher their social status in the community. They were also kept for prestige and pride and also as investment for the young members of the family to fall on in future when they need money. In communities visited as part of the studies, cattle was not used for transportation or ploughing as it is the case in other parts of the country. Here, owners keep them for their meat and for other social functions such as marriage. Occasionally, matured and healthy livestock are sold out to other farmers for breeding purposes.

In computing the cattle water productivity, this study took into account the income made out of selling matured livestock and for ploughing during the main season. The other products such as milk and skin for leather were not considered because they are not sold but few of the owners and other individuals make use of them when necessary. In the case of sheep and goat they were kept and sold for supplementary income for the up keep of the home and also used for some customary rituals and ceremonies. It must be noted clearly that water for feed preparation and for slaughtered livestock processing to get the finished products for final consumption were not included in the computation of LWP because of lack of available data.

From the analysis done in Table 5.5, sheep water productivity was higher than that of goats because they are preferred by Muslims for sacrifices and also because they are larger in size than the goats although their daily water consumption is approximately the same. Cattle had the highest water productivity of them all. The daily water consumption for these animals in the study areas showed no significant difference from similar works done by Houenon (2010) in Burkina Faso and Yamoah-Antwi (2009) in the Upper East region of Ghana and FAO (1986) in sub-sahelian countries. The water productivities per cattle, sheep and goat were found to be respectively: 84.5GH¢/m^3, 32.43GH¢/m^3 and 25.48GH¢/m^3. With this, there is a clear indication that livestock water productivities under the prevailing conditions are higher than that of crops water productivities in the study areas.

Table 5. 5: Computation of Livestock Water Productivity for the Dry Season of 2011

	A	**B**	**C**	**D**	**E**	**F**	**G = F x 5 x 30**	**H = (C + D + E)/G**
Livestock Type	**Price (Matured)**	**Average annual price (GH¢)**	**Average price (B) reduced to five months (GH¢)**	**Transport (GH¢)**	**Ploughing (GH¢)**	**Daily water consumption (m^3)**	**Total water consumption (m^3)**	**Livestock water productivity (GH¢/m^3)**
Cattle	400	72.7	30.3	-	350	0.03	4.5	84.5
Sheep	70	46.7	19.46	-	-	0.004	0.6	32.43
Goat	55	36.7	15.29	-	-	0.004	0.6	25.48

5.7 Agricultural Land Productivity (ALP)

From the various intervention sites, the allocated individual farmlands or plots in the irrigable areas were measured as indicated earlier. The computation of the ALP was done using equation (4.8). The table below indicates the values realised from the various sites in reference to each crop studied.

Table 5. 6: Agricultural Land Productivity (t/ha) for Studied Intervention Sites

ALP (t/ha)			
Intervention Sites	**Tomato**	**Pepper**	**Onion**
Babile	15.7	7.9	8.8
Busa	19.6	1.6	-
Bihee	16.8	1.6	-
Yeliyili	10.9	2.2	-
Kunzokala	7.3	2.4	-
Siiru	6.8	2	2.8
Gbetuore	-	4.5	-
Average ALP	12.9	3.2	5.8
MoFA Standard	**10 – 20**	**7 - 10**	**15 - 20**
FAO Standard	**45 – 65**	**15– 20**	**35– 45**

From Table 5.6 it can be observed that the agricultural land productivity at the intervention sites studied within the Black Volta basin catchment in the Upper West region of Ghana had for tomato a range of 6.8t/ha – 19.6t/ha and comparing this with the MoFA field standards of between 10t/ha – 20t/ha, then most are good with the exception of Kunzokala and Siiru where the values obtained were below the minimum of 10t/ha. But in general, comparing the field values obtained for all the crops studied under the various interventions to the FAO standards for crop grown under semi-arid to arid climatic conditions under high crop and water management practices, the obtained values are very low.

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Based on the results, analysis and discussions of this research work the following conclusions are drawn; that AWM Interventions that allow individual farmers to irrigate independently throughout the season should be encouraged (motorized pumps and shallow well where water table is high) and its use expanded as they produced good crop water consumption factor.

It can also be concluded that for all the agricultural water management interventions considered, the potential to increase agricultural water productivity exist since they either over irrigate or under irrigate with the highest occurring in gravitational flow based interventions.

Livestock had high water productivity as compared to crops but it is worth noting that water for feed production and processing of livestock to get finished products were not considered. Cattle in this part of the catchment were not used for any farm base activity nor for transportation during the dry season.

It also came out that the crops PCWP, EWP and ALP were generally low as compared to FAO standards for areas having such biophysical characteristics. It was noted that local market forces existing in an area influences the EWP of particular crops in that locality.

This research can conclude that efficient application of agricultural water to crops at the right time produced good yields under good agronomic practices and that farmers' knowledge on crop water requirement for particular crops is virtually non-existent.

6.2 Recommendations

From the study the following recommendations are made:

- That GIDA and MoFA should employ competent water resources engineers and managers to help advice, design and develop strategies to improve and sustain agricultural water productivities for the country with the three northern regions in focus.
- Training sections and seminars be organised for farmers, irrigation agronomist and agricultural extension agents on water management and crop water requirements to help reduce water wastage at the intervention sites.
- Further research should be conducted at each specific intervention location to ascertain site specific biophysical parameters and impact of farmer attitude on the interventions in order to establish its influence on PCWP and develop strategies to boost EWP of crops grown in the dry season.
- Further research is needed in the field of livestock water productivity which will take into consideration water used in producing livestock feed and water used in the processes to get finished products on to markets.

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APPENDICES

Appendix A: Flow rate and frequency of irrigation for the entire period

AWM Intervention sites	Average flow rate, Q (m^3/s)	Pumping rate, Q (m^3/s)	Remarks
BABILE	0.0434		Irrigation is done for three hours every other day for the period.
BUSA		(using a 15 lt container)	Irrigation is done for four hours every other three days for the entire growth period and also with shallow wells.
BIIHEE		(using a 12 lt container)	Irrigation is done by the abstraction of water from the hand dug shallow wells located at various places within the farm land.
GBETUORE		(using a 18 lt container)	Irrigation is done by the use of motorized pumps to abstract water from the Black Volta river for 10 hours.
SIIRU		(using a 12 lt container)	Irrigation is done weekly and the valve is open for twenty four hours for the whole period.
KUNZOKALA		(using a 15 lt container)	Irrigation is done using bucket and line, and motorized pumps for the abstraction and delivery of water to the fields.
YELIYIRI	0.161		Irrigation is done weekly for the period and the valve is open for eleven hours.

Appendix B: Standard trade weights and prices as at 2011

CROP	MEANS OF TRADE	UNIT STANDARD WEIGHT (kg)	PRICE (GH¢)
Tomato	crate	52	50
Pepper	sack	20	50
Onion	sack	73	100

Appendix C: Location of agricultural management intervention sites

AWM Intervention sites	Location	
	Latitude (N)	Longitude (W)
Yeliyili Dam	9.88	-2.59
Gbetuore	10.44	-2.83
Kunzokala Dam	10.52	-2.75
Siiru Dam	9.93	-2.55
Biihe	9.99	-2.39
Busa Dam	10.01	-2.39
Babile Dam	10.55	-2.86