KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY, KUMASI, GHANA

PRODUCTIVITY OF STORED WATER IN SMALL RESERVOIRS IN THE WHITE VOLTA BASIN, BURKINA FASO

Vignon Nada Ibidoun Franck Ouinsou Houenou

February 2010

WRESP-KNUST

Faculty of Civil and Geomatic Engineering

Department of Civil Engineering

PRODUCTIVITY OF STORED WATER IN SMALL RESERVOIRS IN THE WHITE VOLTA BASIN, BURKINA FASO

Master of Science Thesis

By

Vignon Nada Ibidoun Franck Ouinsou Houenou

Supervisors

Prof. Samuel Nii Odai

Mr. Frank Ohene Annor

Kumasi

February 2010

PRODUCTIVITY OF STORED WATER IN SMALL RESERVOIRS IN THE WHITE VOLTA BASIN, BURKINA FASO

By

Vignon Nada Ibidoun Franck Ouinsou Houenou

A Thesis Submitted to the

Department of Civil Engineering

Kwame Nkrumah University of Science and Technology

in partial fulfillment of requirements for the award of the Degree of

MASTER OF SCIENCE

in

Water Resources Engineering and Management

Faculty of Civil and Geomatic Engineering

College of Engineering

February 2010

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.

Vignon. N. I. F. Ouinsou Houenou 20/04/10

Signature Date

Certified by:

Prof. Samuel Nii Odai 20/04/10

(Principal Supervisor) Signature Date

Mr. Frank Ohene Annor 26/04/10

(Second Supervisor) Signature Date

Prof. S. I. K. Ampadu 04/05/2010

(Head of Department) Signature Date

Dedication

IN MEMORY OF JOSEPHINE KOUTON, MY MOTHER.

Abstract

Water scarcity is a major factor limiting food production. In an environment of water scarcity, formulation of strategy for the effective, efficient allocation among sectors and utilization of scarce water resources is required, and water productivity can be used as indicator in comparing the various uses of water. This study was conducted during the dry season and aims at quantifying agricultural (crop and livestock) productivity of stored water in small reservoirs in the White Volta Basin in Burkina Faso. Primary data was collected through focus group discussions, interviews, field observation and measurement. Seven reservoirs were selected. The results show that crops grown during the dry season are mainly vegetables namely cabbage, onion, pepper, and tomato. Cabbage was the most productive. Cattle was found to have the highest productivity followed by donkey, sheep and goat. The study concluded that crop water productivity is low compare to the productivity computed based on FAO standards for good yields in semi – arid and arid regions and attempts to improve crop water productivity must recognize controlled application of water to crops.

Keywords: Crop, Livestock, water productivity, White Volta Basin, Burkina Faso.

Table of content

Acknowledgement

I am grateful to:

The Almighty God for his guidance and wisdom that accompany me through this experience successfully.

My father Augustin Ouinsou, my brother Marx, my sisters Elsie and Sprancia and my friend Angele Marandet.

My supervisors Prof. Samuel Nii Odai and Mr. Frank Ohene Annor for their invaluable contributions.

Mr. Emile Tonde, Mr. Soumaila Kabre and Mr. Alidou Kongo for their support on the field during my data collection process.

My friends and course mates especially Mr Adu-Dankwa Eric, Mr Ephraim Sekyie-Annan, Mr Mark Amo-Boateng and Mr Samuel Barnie.

The International Water Management Institute (IWMI)

List of Figures

List of Tables

List of Plates

List of Abbreviations and Acronyms

CPWF: Challenge Program on Water and Food

CWP: Crop Water Productivity

ELP: Economic Land Productivity

EWP: Economic Water Productivity

FAO: Food and Agriculture Organization of the United Nations

ITCZ: Inter-Tropical Convergence Zone

LWP: Livestock Water Productivity

PWP: Physical Water Productivity

UNESCO: United Nations Educational, Scientific and Cultural Organization

UNDP: United Nations Development Programme

USGS-GLCC: United States Geological Survey-Global Land Cover Characterization

VBRP: Volta Basin Research Project

WUeff: Water Use efficiency

CHAPTER ONE

1 INTRODUCTION

1.1 Background

Burkina Faso is located in the Sudano-Sahelien Zone, where the climate is semi arid; rainfall is low, erratic and characterized by strong inter-annual and space variability and its volume also decreases from the south-west to the north. The temperature varies largely with the seasons and characterized by high ranges at night, particularly in the north of the country (Sivakumar *et al.*, 1994).

Burkina Faso has a quite dense hydrological network, however most of these rivers are not permanent (Ouedraogo *et al.*, 2006). As much as 16% of the rainfall infiltrate the soil that contains few aquifers and a further 4% find its way into the rivers which stream rapidly to Ghana and end up in the Gulf of Guinea. An important quantity of rain water is lost through leaching and run-off into major rivers (Abdou-Salam, 2006). According to the World Meteorological Organization, annual water demand in Burkina Faso surpasses available water resources by between 10% and 22% (Abdou-Salam, 2006). These conditions call for action, in particular for increased investment in water resources (ie: infrastructure).

The Burkina Faso government's efforts are therefore directed toward construction of small reservoirs. Burkina Faso has over 2000 storage reservoirs (including small, medium and large dams) with a total storage capacity of 6 km^3. The stored water is mainly used for irrigation, livestock watering, domestic water supply and hydropower. The total renewable water resources is estimated at 17.5 km^3 (CIA World factbook, 2001) and freshwater withdrawal is estimated at 0.8 km^3 per year with domestic needs representing 13%, industrial representing 1%, and agriculture representing 86% (CIA World factbook, 2000). During the dry period of the year, most of the people living in the rural areas in the semi-arid environment depend mainly on the water stored in the small reservoirs for the sustenance of their livelihood (Liebe *et al.*, 2005; Poolman, 2005; Balzacs, 2006)) resulting in the use of the water for various activities such as domestic use, dry season irrigation, livestock watering and other beneficial uses (Rusere, 2005). However, the overdependence on some of the small reservoirs associated with inadequate capacity and high evaporation enable the stored water to last for a complete dry season (Manzungu, 2002).

In the future, an expected consequence of water scarcity will be an increased competition for water between agriculture and other sectors such as the environment and urban water demand (Tropp *et al.*, 2006). Irrigated agriculture which accounts for about 80% of blue water withdrawal in developing countries will be more affected by water scarcity than other sectors (UNDP, 2006). Moreover, the incapacity of irrigated agriculture to compete economically with other sectors for water compound the problem of water scarcity in irrigated agriculture. However, in most of the developing countries where the economy is agriculture-based, water supply plays and will continue to play an essential role in meeting demands for food for the growing population and in supporting the livelihood of the poor majority. Water development and management through the development of new and innovative approaches is essential to feed more than 800 million hungry people in the world, and ensure safe drinking water for more than 1.1 million people who have currently no access to it (Annan, 2002; Inocencio *et al.*, 2003). Increasing productivity of stored water in small reservoirs will lead to making more water available for other human and ecosystems uses (Sharma, 2006).

This thesis aims to quantify agricultural productivity of stored water in small reservoirs in the White Volta Basin in Burkina Faso. The need for this study arises from the facts that in such an environment of economic water scarcity, formulation of strategies for the effective, efficient allocation among sectors, crops and even regions, and utilization of scarce water resources is required (Molden *et al.*, 2001) and water productivity can be used by decision makers as an indicator in comparing the various uses of stored water (Cook *et al.*, 2006).

1.2 Problem statement

Similar to most of the sub-Saharan African countries, Burkina Faso is characterized by economic water scarcity (Molden, 1997)). Per capita water availability is declining (i.e. 1,517 m^3/cap/year in 2000 to an estimated 378m^3/cap/year by 2050) (The Atlas of Water, 2004) due mainly to population growth and climate change. Moreover, demand for the scarce water resource from the nonagricultural sectors (domestic, industrial and environmental) is rapidly increasing (Rosegrant *et al.*, 2002). In the past, new investments in irrigation and water supply systems and improvement in management was used to meet the growing demand for the scarce water resources (Rosegrant, 2003). Therefore, considerable attention was given to the supply-side management. However, because of the rapid growth in the demand for water and the dwindling per capita water availability and the high cost of developing new water infrastructure (i.e. reservoirs), shifting from supply-side to demand-side management is now viewed as a viable option in water management policies.

The rising role of demand management is partly related to the increased role of economics which provides means to evaluate and foster both equity and efficiency in water resources management.

1.3 Justification

According to Cook *et al.*, (2006), estimates of water productivity can be used to identify the level of water-use efficiency of a system under study and to provide understanding into the opportunities for better water management towards increased water productivity for the scale under consideration. By improving water productivity in agriculture, the demand for scarce water resources will be reduced, environmental degradation will be lessened and food security will be enhanced simply because by providing more food with less water makes the saved water available to other natural and human uses (Rijsberman, 2001). Additional freshwater withdrawal needed to feed the world's growing population can be reduced to zero with an increase of water productivity in agriculture by 40% (Molden *et al.*, 2001).

Improving water productivity is one important strategy for addressing future water scarcity which is driven particularly by population growth and potential changes in climate and land use.

1.4 Objective

The main objective of this research is to determine the agricultural productivity of stored water in small reservoirs in Burkina Faso.

The specific objectives of the research are to:

- Select small reservoirs
- Estimate water consumption for their agricultural purposes
- Quantify agricultural water productivity (physical and economic) of the stored water in the selected reservoirs

- Quantify the crops water use efficiency

CHAPTER TWO

2 LITERARURE REVIEW

2.1 Introduction

The purpose of this literature review is to present brief understanding of small reservoirs and water productivity.

2.2 Small reservoirs

Various world organizations and countries define small reservoirs in terms of height of the dam wall and/or storage capacity of the reservoir (Table 2.1).

Table 2.1: Some definitions of Small Reservoir

Organization / Country	Height (m)	Capacity (m^3)
World Bank[1]	< 15	
World commission on Reservoirs[1]	< 15	50000 - 1 x10^6
United State of America (USA)[1]	≤ 6	0.123 x 10^6
Government of Zimbabwe[2]	≤ 8	≤1 x10^6

Sources: [1]Senzanje and Chimbari (2002), [2]Mamba (2007)

2.3 Water productivity

Productivity is a measure of system performance expressed as a ratio of output to input. Productivity may be used to assess the whole system under study or parts of it. Also, productivity could account for all or one of the inputs of the production system (Molden, 1997):

- Total productivity: ratio of total tangible outputs to total tangible inputs
- Partial or single-factor productivity: ratio of total tangible output to input of one factor within a system.

This study uses the concept of single factor productivity.

Water productivity was introduced to implement existing measures of the performance of irrigation systems, mainly the classic irrigation and effective efficiency (Keller *et al.*, 1996). Classic irrigation efficiency focuses on establishing the nature and extent of water losses and included storage efficiency, conveyance efficiency, distribution efficiency and application efficiency. Effective efficiency is the amount of beneficially-used water divided by the amount of water used during the combined processes of conveying and applying water (Keller *et al.*, 1996).

According to Molden *et al.*, (2003), water productivity is a single-factor productivity that measures how a system converts water into goods or services. Water productivity can be used to compare water use systems in space and time. There are two possible ways to express water productivity:

- Physical water productivity: the mass of output per unit of water applied
- Economic water productivity: the value of output per unit of water applied

The unit of water is important in computing water productivity of a system and can be expressed as water delivered to a use (i.e. crops) or water depleted by a use (i.e. livestock).

2.3.1 Crop water productivity (CWP)

The common measure of crop water productivity has been the amount of output per unit area such as yield in tons per hectare. But, since water becomes scarcer, water productivity that considers the output per unit of water has become more relevant.

Crop water productivity (CWP) is generally defined as the amount or value of product over volume of water delivered during the crop's entire growth period. Physical crop water productivity (PWP) is obtained by dividing the crop yield by the volume of water delivered during the crop's entire growth period and the economic crop water productivity (EWP) is computed as the income from sale of the crop yield divided by the volume of water delivered during the crop's entire growth period.

Crop water productivity can be considered at different spatial scales (Cook *et al.*, 2005):

- Crop scale: is of interest to crop physiologists to assess how efficient a particular crop or cultivar of a crop is in converting water into biomass. At this scale the output can be quantified either as total biomass or crop yield (harvestable produce). The water input that is relevant for this assessment is the water used in transpiration.
- Field scale: is of interest to the farmer, agronomist and water specialist to assess how efficient a particular cropping system converts water into beneficial output and the opportunities of saving water lost through non-beneficial use (e.g.: evaporation). At this scale the output can be quantified as total biomass or crop yield and the water inputs are the amount of water that was delivered to the crop.
- Irrigation system scale: is of interest to the irrigation system manager in assessing how productive the water available to the irrigation system is being used. At this scale the

manager takes into consideration both the amount of water delivered to the crops and that which is recaptured for re-use downstream. The output can be quantified in physical and economic terms and the water can be accounted for in either volume or in value terms.

Physical crop water productivity is also defined as the crop yield divided by the cumulative amount of transpiration or evapotranspiration (Mdemu, 2008)

In this study, crop water productivity will be considered at field scale. The formula described by Lemoalle (2006) will be adopted for the computation of the crop water productivity in which the denominator will be considered as the volume of water applied or delivered to the crop, not the amount of transpiration or evapotranspiration. Computation of crop water productivity based on the amount of transpiration or evapotranspiration may not reflect the productivity of the stored water in the reservoirs. It puts more emphasize on the volume of water used by the crops rather than the volume of water applied to the crops or used by the farmers to irrigate the crops. The computed productivity is then based on the amount of water used by the crops, not the amount of water used in irrigating the crops which is the centre of interest in this study.

$$CWP = \frac{\text{Crop Yield}\,[\text{kg}]}{\text{Water Applied}\,[\text{m}^3]} \quad [\text{kg/m}^3] \qquad \text{(Lemoalle, 2006)}$$

Or

$$EWP = \frac{\text{Revenue obtained from Crop Yield}\,[\text{Euro}]}{\text{Water Applied}\,[\text{m}^3]} \quad [\text{Euro/m}^3]$$

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).

Water used by livestock for drinking is relatively small, less than 2% of the total water used, as compared to the amount utilized in producing the feed that they consume. The total water used by livestock is assumed to include only water either directly consumed by the animals or used for cleaning and other services functions during the processing of animal production. The sources of livestock water consumption may be cited as (Zinash et al, 2002):

- Drinking water
- Water contained in feeds

Livestock services and products include among others meat, milk, hide, manure, ploughing and transport. In this study, livestock water productivity will be computed using the formula by Peden and Tadesse (2003):

$$LWP = \frac{\text{Livestock Product [Euro]} + \text{Livestock Services [Euro]}}{\text{Water consumed [m}^3\text{]}} \quad [\text{Euro /m}^3]$$

This study takes into consideration only the amount of water consumed by livestock because the feed are produced under rainfed agriculture.

2.4 Water use efficiency

Water use efficiency (WU_{eff}) is the ratio between the net crop irrigation water requirement (NIR) and the volume of water that reaches the irrigation plots and that is effectively applied to the crops (Vapp) (Oweis *et al.*, 2003, Kijne *et al.*, 2003). Water use efficiency is also called consumed fraction (Willardson *et al.*, 2002; Clemmens and Burt, 1997; Molden, 1997).

$$WUeff = \frac{NIR}{Vapp}$$

The net crop irrigation requirement can be computed using the CROPWAT model.

The CROPWAT model was initially developed by the FAO in 1990 for the purpose of planning and managing irrigation projects. CROPWAT4W, the latest version, under windows interface was formulated by the FAO, together with Southampton University of UK, and National Water Research Center (NWRC) of Egypt.

CROPWAT model by Food and Agriculture Organization (FAO) is used to estimate net crop irrigation water requirements (NIR). NIR is defined as the amount of water in addition to available soil moisture from precipitation that crop plants on irrigated land must receive to grow without water stress. The CROPWAT model used the equation below to compute NIR.

$$NIR = k_c \times ET_o - P_{eff} \quad (1)$$

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

Crop coefficient, *kc* is a function 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.

According to Smith (1991), effective rainfall can be calculated using common empirical methods:

- Fixed percentage of rainfall

$PE_{eff} = a \times P_{tot}$

Where PE_{eff} is the effective rainfall; a is a fixed percentage coefficient (specified by the model user), with a typical range of values from 0.7 to 0.9; and P_{tot} is the measured or generated total daily rainfall.

- Dependable rainfall

The FAO developed this empirical formula to estimate dependable rainfall. This method may be used for design purpose where 80% of probability of exceedance is required.

For $P_{tot} < 70$ mm; $PE_{eff} = 0.6\ P_{tot} - 10$

For $P_{tot} > 70$ mm; $PE_{eff} = 0.8\ P_{tot} - 24$

- USDA Soil Conservation Service method

$PE_{eff} = P_{tot} \times (125 - 0.2P_{tot})/125$ for $P_{tot} < 250$ mm

$PE_{eff} = 125 + 0.1 \times P_{tot}$ for $P_{tot} > 250$ mm

where,

PE_{eff} is effective rainfall (mm) and P_{tot} is total rainfall (mm)

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.

$$ET_o = \frac{\Delta \frac{(R_n - G)}{\lambda_w} + \rho_a C_p \frac{(e_s - e_a)}{\lambda_w}}{\Delta + \gamma_a \left(1 + \frac{r_c}{r_a}\right)}$$

where ET_o is potential evapotransipiration [mmd^{-1}], R_n is the net radiation [$MJm^{-2}d^{-1}$], G is soil heat flux [$MJm^{-2}d^{-1}$], (e_s-e_a) represents the vapour pressure deficit of the air [kPa], ρ_a is the mean air density at constant pressure [kgm^{-3}], Cp is the specific heat of the air [$MJkg^{-1}$ $°C^{-1}$], Δ represents the slope of the saturation vapour pressure-temperature relationship [$kPa°C^{-1}$], λ_w is the latent heat of vaporization [$MJkg^{-1}$], γ_a = psychrometric constant [$kPa°C^{-1}$], r_c is crop resistance [sm^{-1}], and r_a is aerodynamic resistance [sm^{-1}].

To compute the net crop irrigation requirement CROPWAT model requires the data below:

- Climatic data – mean monthly maximum and minimum temperatures (^oC), monthly rainfall (mm), relative humidity (%), sunshine duration (hours) and wind speed (m/s)
- Crop data – the crop type and planting date

The climatic data can be exported from CLIMWAT 2.0 which is a climatic database that is used in combination with CROPWAT. CLIMWAT allows the calculation of crops water requirements, irrigation supply and irrigation scheduling for various crops for a range of meteorological stations worldwide (FAO, 2009).

CLIMWAT offers long-term (at least 15 years) monthly mean values of seven climatic parameters, namely:

- Mean daily maximum and minimum temperature in ^0C

- Mean relative humidity in %
- Mean wind speed in km/day
- Mean sunshine hours per day
- Mean solar radiation in $MJ/m^2/day$
- Monthly rainfall in mm/month
- Reference evapotranspiration calculated with the Pennan-Montheith method in mm/day

CHAPTER THREE

3 STUDY AREA

The study was conducted within the White Volta Basin, which is a sub-basin of the Volta Basin (Figure 3.1). Due to data unavailability, this chapter provides a short description of the White Volta Basin complemented by a general description of the Volta basin.

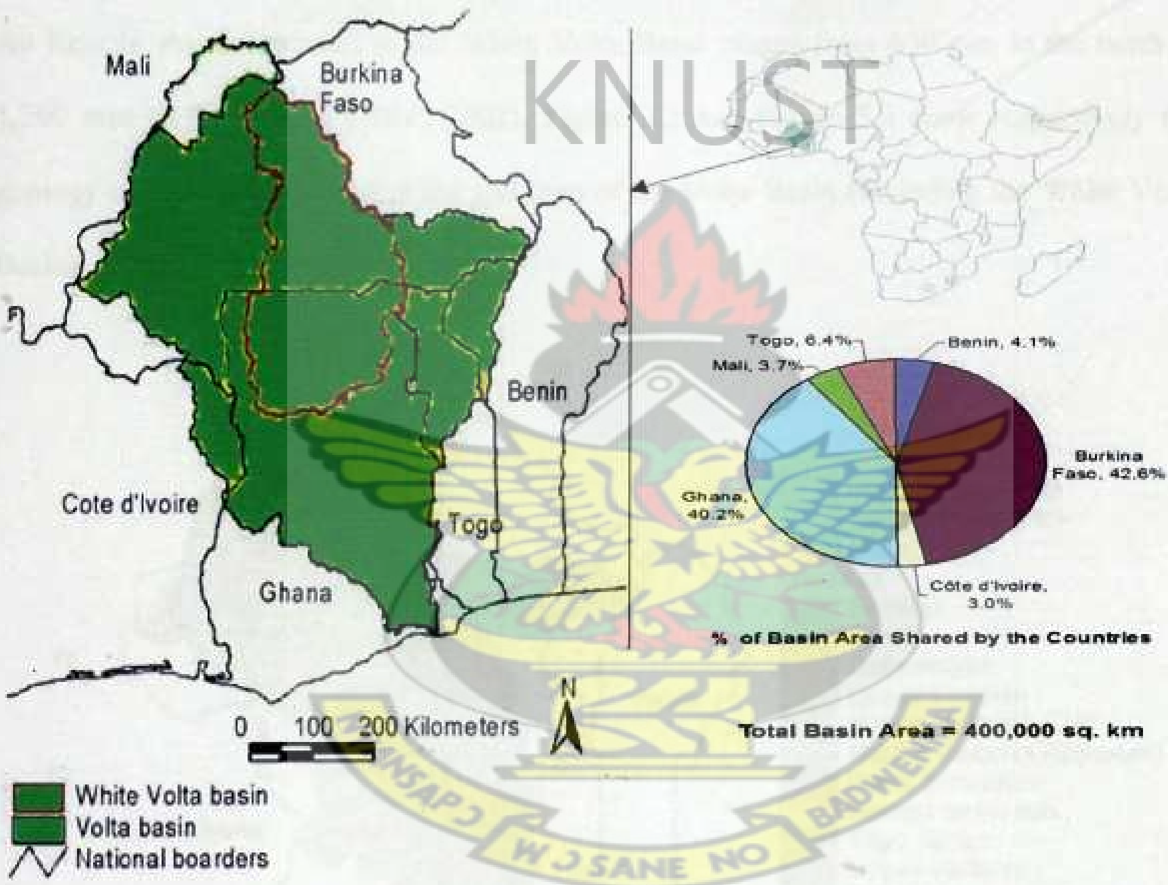

Figure 3.1: Location of the Volta Basin and the White Volta Basin (Rodgers et al, 2007. Modified).

3.1 White Volta Basin Overview

The White Volta Basin (94,044 km^2) which is located upstream of Lake Volta in Northern Ghana and Burkina Faso, has very flat topography particularly in the southern part (<0.1%) (Wagner *et al.*,2006). Guinea savannah and Sudan savannah are the most predominant land use types respectively in the southern and northern part. Precambrian platform and a sedimentary layer are the main geological systems of the basin. The predominant soil types are lixisols. Annual rainfall in the White Volta Basin ranges from 600 mm in the north to 1,200 mm to the south (VBRP, 2002). Figure 3.2 and Figure 3.3 show respectively the geology of the Volta Basin and the soil map of the Volta Basin (including the White Volta Basin)

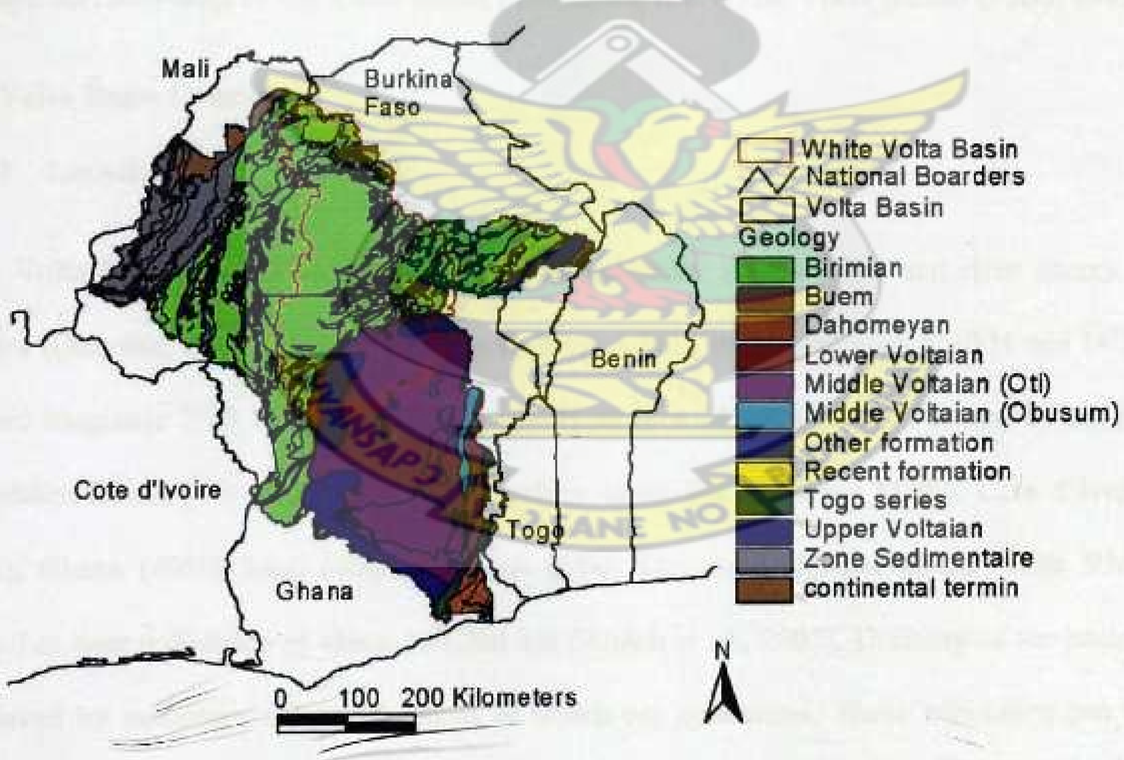

Figure 3.2: Geology of the Volta Basin (including the White Volta Basin) (Source: Obuobie, 2008)

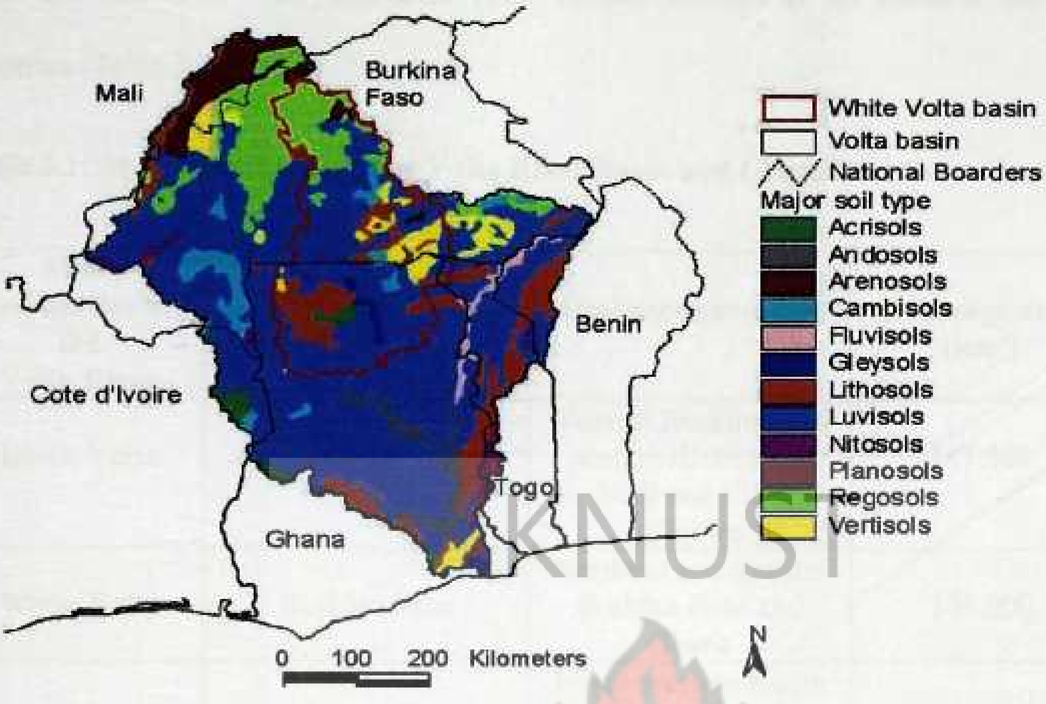

Figure 3.3: Soil map of the Volta Basin (including the White Volta Basin) (FAO, 1995)

3.2 Volta Basin Overview

3.2.1 Location

The Volta Basin, one of the eighty (80) internationally shared lakes and river basins in Africa (Obuobie, 2008), (Figure 3.1) lies in West Africa, within latitudes 5°30 N and 14°30 N and longitude 2°00 E and 5°30 W. It covers an area of 400,000 km^2, shared by six (6) countries: Benin (4% of the total basin surface area), Burkina Faso (43%), Cote d'Ivoire (3%), Ghana (40%), Mali (4%) and Togo (6%). The main channel of the Volta River stretches over a distance of about 140,000 km (Andah *et al*., 2005). Draining of the basin I achieved by numerous tributaries, most of which are ephemeral. These tributaries can be grouped into four main river systems: the Black Volta, White Volta (Nakambe), Lower

Volta and Oti River. The tributaries drain various portions of the basin in the riparian countries (Table 3.1).

Table 3.1: Main tributaries of the Volta River Basin and Characteristics

Main tributaries of the Volta River	Source of River	Drainage coverage	Drainage area (km^2)
Black Volta	Mali	Western Burkina Faso and small areas in Mali and Cote d'Ivoire	147,000
White Volta	Burkina Faso	Northern and Central Burkina Faso and Ghana	106,000
Oti	Burkina Faso	North-western Benin and Togo, south-eastern Burkina Faso and Ghana	72,000
Lower Volta	Ghana	Middle to southern parts of Ghana	73,000

Source: Rodgers et al., 2007 (modified)

3.2.2 Climate

The climate of the Volta Basin is controlled by the movement of the Inter-Tropical Convergence Zone (ITCZ). The ITCZ is the inter-phase of the hot, dry and dusty northeast trade wind that blows over the sea from the south Atlantic. The movement of the ITCZ is characterized by strong frontal activities, which influence the amount and duration of rainfall over the basin (Amisigo, 2005; Andah *et al*., 2003).

The Volta Basin is characterized by two major climatic zones: the humid south with two distinct seasons of rainfall that peaks in June and September, and the tropic north with one rainfall season that peaks in August/September. The rainfall in the humid south zone is evenly distributed over the year while in the tropic north it is poorly distributed and very much skewed towards the month of June to September during which over 79% of the total annual rainfall occurs (Amisigo, 2005). Average monthly temperatures in both zones are most typically above 25°C.

Although the periods of the rainfall seasons are known, the beginning of the rainy season is unpredictable, making rainfed agriculture a highly risky source of livelihood (Obuobie, 2008).

The mean monthly temperatures decrease from 36°C in March to 27°C in August in the northern parts of the basin and from 30°C in March to 24°C in August in the south (Oguntunde, 2004). The daily maximum temperatures vary from 32°C to 44°C, usually recorded in March to April; while daily minimum temperatures are recorded in December to February and can be as low as about 14°C in January (FAO, 1997). Temperatures increase in a south-north direction.

3.2.3 Land cover and land use

The dominant land cover type in the Volta Basin is savannah (grassland and shrubs). It consists of grassland interspersed with shrubs and trees. The savannah covers about 86% of the entire basin. The other land cover types are (WMI, 2003): croplands and natural vegetation (10.4%), wetlands (4.6%), forest cover (0.7%) and urban and industrial coverage (0.5%).

The dominant land use in the basin is agriculture, which includes the cultivation of annual crops, tree crops, bush fallow and unimproved pasture (FAO, 2000). Agriculture in the basin is largely rainfed and essentially manual with the use of very few external inputs like tractors and fertilizers. A large part of the land in the basin is degraded and less suitable for crop production. Figure 3.4 shows land-cover distribution in the Volta Basin (including the White Volta Basin).

3.3 Agriculture in Burkina Faso

In Burkina Faso, agriculture may be seen as exclusively extensive and dominated by the rainfed system. It is food crop agriculture with low productivity, dependent on climatic hazards and mainly practiced on small scale family farms. Only one third of the total country's arable land are cultivated per year. The main crops are cereals (sorghum, millet, maize, rice and fonio), legumes and tubers (cowpeas, sweet potatoes, yam, and cassava), cash crops (sesame, groundnuts and soybeans), vegetables (tomatoes, onions, cabbage, okra, pepper, green bean and potatoes) and fruits (citrus and bananas) (Ouedraogo *et al.*, 2006). According to Barry et al. (2005), the cropped area in the Volta Basin represents 82.5% of the total cropped land in Burkina Faso.

The economic and social development of Burkina Faso is mainly based on the agriculture, which occupies nearly 86% of the working population and contributes 30% of the GDP. Also, livestock contributes approximately 10% of the GDP and employs around 6% of the active population (Ouedraogo *et al.*, 2006).

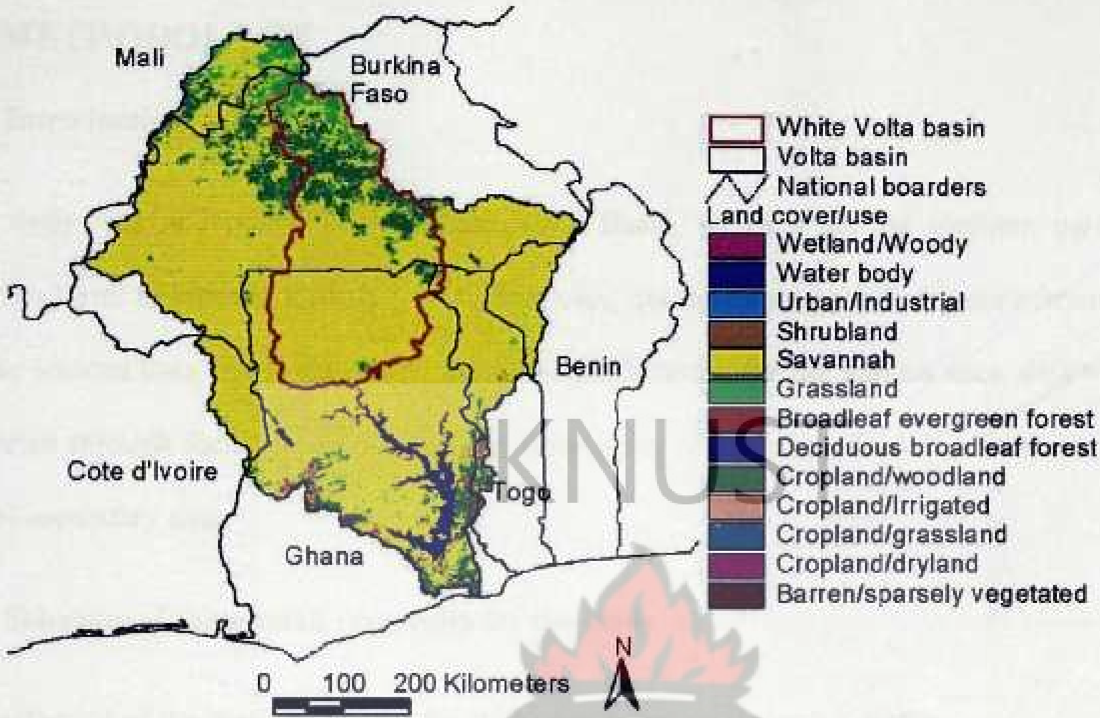

Figure 3.4: Land-cover distribution in the Volta River Basin (including the White Volta Basin) (USGS-GLCC, 2007)

CHAPTER FOUR

4 METHODOLOGY

4.1 Introduction

The study was undertaken in the White Volta Basin, focusing on the southern part of Burkina Faso. In order to identify the multiple uses, quantify the volume of water consumed by the various uses and to determine the water productivity for the various uses, data were collected through focus group discussions, interviews, observation, field measurement and use of secondary data.

4.2 Selection of some small reservoirs for the study

The selection of the small reservoirs for study was achieved through 2 stages.

During the first stage, through desk study and literature review, locations in term of coordinates (longitude and latitude) of some reservoirs in the southern part of Burkina Faso were collected. Using Google Earth, the coordinates were plotted (for about 60 reservoirs) to have an idea of where there is a concentration of reservoirs in the southern part of Burkina Faso in the White Volta Basin. It was found that more than 50 percent of the reservoirs (plotted coordinates) were located in the town of Kombissiri and its neighboring towns such as Koubri, Koudougou, and Ouagadougou.

During the second stage, a trip to the town of Kombissiri was undertaken to survey some reservoirs' sites in order to have an idea of the reservoirs' uses, the method of irrigation and the crops grown. This was done to make the selected reservoirs representative of the study area.

Seven reservoirs were selected for the study and they are located in the White Volta Basin in the southern part of Burkina Faso, precisely in the towns of Kombissiri and Ouagadougou. The criteria for the selection of these small reservoirs took into account the definition of small reservoirs adopted by the World Bank (dam wall height < 15 m) and the multiple uses of the reservoirs particularly dry seasons farming and livestock watering. The selection of the small reservoirs was based on the dam height because data available does not include the reservoirs capacity. Table 4.1 shows the selected reservoirs, their respective province and the town in which they are.

Table 4.1: List of the selected reservoirs with their location

Reservoirs name	Province	Town
Konioudou	Bazega	Kombissiri
Kierma	Bazega	Kombissiri
Pissi	Bazega	Kombissiri
Kagamzinse	Bazega	Doulougou
Naba-Zarma	Kadiogo	Koubri
Kamboinse	Kadiogo	Kadiogo
Yamtenga	Kadiogo	Kadiogo

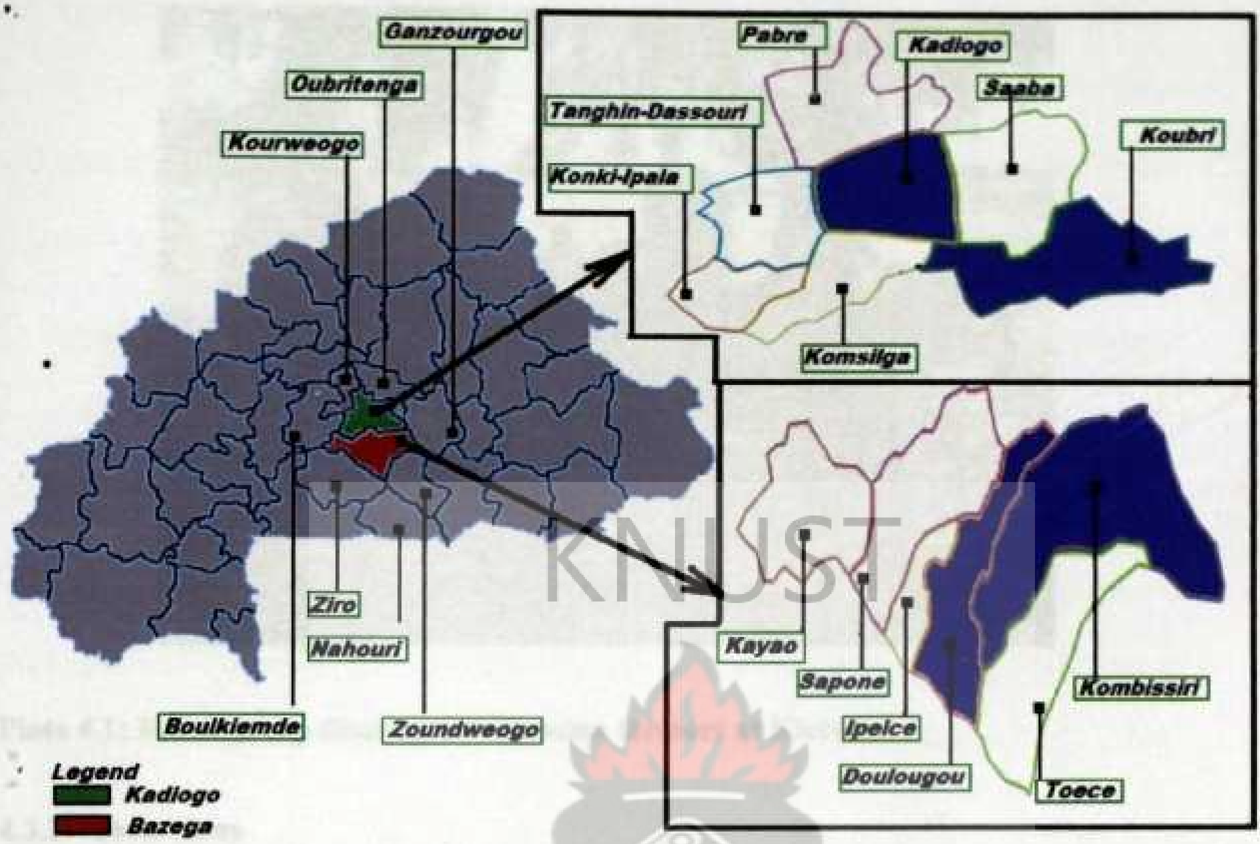

Figure 4.1: Map showing the location (province) of the selected reservoirs

4.3 Data collection

4.3.1 Focus group discussions and questionnaire

Through focus group discussions, questionnaire was administrated orally mainly to dry season farmers of all the selected reservoir sites and livestock owners in the areas. The questionnaire was administrated with the help of a translator who understands French and is able to converse in the local language (i.e. ''More''). The questions were asked to the translator in French who asked the farmers and livestock owners in the local language. The data collected included the various uses of the reservoirs, the various crops grown, the crops growing period, the crops yield, the irrigation method, the irrigation frequency, livestock watering method and services, and prices of crops and livestock.

Plate 4.1: Focus group discussion with some farmers at Kierma

4.3.2 Interviews

Interviews were conducted with some extension officers delegated by the Centre Regional de Production Agro-pastorale (Regional Center of Agricultural Production). The interviews were conducted (after the focus group discussions) to obtain more understanding of the practices and the history about the reservoirs. The interviews were also necessary to confirm the information collected through the focus group discussions and questionnaires held with the dry season farmers and livestock owners.

4.3.3 Observation and secondary data

Observations were done at the reservoir sites to confirm the information collected through focus group discussions.

Also, in addition to the primary data, secondary data were collected from some institutions such as the Ministry of Agriculture and Water Resources, the Head Office of Water Resources, the Head Office of Agriculture Statistics, the Head Office of Planning and development of Irrigation, the group 2ie-EISHER.

The secondary data included among others water demand and projection of water uses, some reservoirs locations, storage volume and area, studies done on agricultural uses of reservoirs which show livestock water consumption and water requirements for some crops.

It has been found that farmers at the reservoirs sites use pumps to irrigate hence, the pumping rates for some pumps were determined through measurements using a container of known capacity and a stopwatch. Also, cropping areas were measured using measuring tape.

4.3.4 Water productivity quantification

(a) Crop water productivity

Physical crop water productivity was computed using the following formulae:

$$CWP = \frac{\text{Crop Yield}[\text{kg}]}{\text{Water Applied}[\text{m}^3]} \qquad [\text{kg/m}^3] \qquad \text{(Lemoalle, 2006)}$$

Crop yield was collected through interviews and focus group discussions. Farmers estimated the yield in terms of weight (kg), bags and crates. However, bags and crates filled with crops were weighed, and values obtained were found to show no difference with the values said by the farmers. This is due to the fact that during the selling process, farmers' products were weighed and weight is known by the farmers. Also extensions officers were able to give information about crops yields, which helped to confirm information given by farmers.

Water applied to the crop was computed based on the measured pump rates, the crop growth period, the frequency of irrigation and the duration of irrigation obtained through field measurement, interviews and focus group discussions. Water applied was then computed as:

Water applied (cu.m) = No of irrigationdays (days) x Duration of irrigation(second) x Pump rate (cu.m/s)

Using a calendar, the number of irrigation days was calculated based on the crop growth period and the irrigation frequency (i.e. every 3 or 4 days)

Economic water productivity was computed using:

$$EWP = \frac{\text{Revenue obtained from Crop Yield [Euro]}}{\text{Water Applied [m}^3\text{]}} \quad \text{[Euro /m}^3\text{]}$$

In using this formula, the numerator was computed as:

Revenue obtained from crop yield (Euro) = Crop yield (kg) x price of crop (Euro/kg)

Knowing the crops water productivity is important but it will also help more to know how good the crops' water productivity is and if there is a possibility to increase it. In this study, FAO ranges for good yields (in t/ha) in semi-arid and arid regions for crops considered in this study, under irrigation under high level of crop and water management were compared to the yields obtained from the study area. And to obtain a common background in comparing the crops water productivity, FAO ranges in yields were converted into physical water productivity by dividing the minimum value of the range by the net crop water requirement (that is assuming 100% crop water use efficiency). The physical water productivity was then multiplied by the crop price to obtain the economic productivity. In addition to that, economic land productivity was also obtained by multiplying the minimum value of the range by the price of the crop price obtained in the field. Table 4.2 and Table

4.3 below show respectively the FAO range for good yields and water productivity computed based on the FAO range for good yields.

Table 4.2: FAO range for good yield for crops under irrigation in semi – arid and arid climatic conditions under high level of crop and water management.

Crops	FAO yield range (t/ha)
Cabbage	40 – 60
Onion	35 – 45
Pepper	15 – 20
Tomato	45 – 65

Source: FAO

Table 4.3: Water productivity computed based on the FAO range for good yield.

Productivity	Cabbage	Onion	Pepper	Tomato
PWP (kg/m^3)	7.9	7.2	2.23	5.53
EWP (€/m^3)	0.7	1.4	0.49	0.74

(b) Livestock water productivity

Livestock water productivity was computed using:

$$LWP = \frac{\text{Livestock Product [Euro]} + \text{Livestock Services [Euro]}}{\text{Water consumed [m}^3\text{]}} \quad \text{[Euro /m}^3\text{]}$$

Cattle, donkey, goat and sheep were considered in this study. The selling price of cattle, donkey, goat and sheep were considered as their respective product revenue. The cost of using cattle for ploughing activity for an entire growing season was taken as cattle services. For donkey, in addition to the cost of using it for ploughing activity, since donkey is used for transportation, the average revenue of servicing donkey as means of transportation was also taken into account while computing revenue obtained from donkey services. In summary, goat and sheep product and service were considered only as their sale, cattle product and services were taken as their sale and their use for ploughing and donkey product and services took into consideration the sale of donkey, the use of donkey for ploughing and for transportation.

The average livestock ploughing and transportation cost considered were for the entire dry season. For the selling price, the cost of a mature livestock was considered. Considering a maturity age of 5, 5.5 and 1.5 years respectively for cattle, donkey and goat/sheep. To ensure that the water productivity computed reflected that for the dry season and also to ensure an equal base for comparison with the crop water productivity, the price of selling the livestock was divided by its maturity age (in terms of months) and multiplied by the duration of the dry season. Table 4.4 shows the computation of livestock water productivity.

Estimates of the volume of water consumed by livestock, per day were obtained from secondary data. The secondary was obtained from ONEA (National Board of Water and Sanitation). The institution has estimated among other water demand sector, livestock water consumption specifically for Burkina Faso. Water consumption was estimated for cattle, donkey, goat and sheep per head and per day (39.2 L/day/head for cattle, 23 L/day/head for donkey and 4.3 L/day/head for both goat and sheep).

Table 4.4: Computation of livestock water productivity

	A	B	C	D	E	F	G = F x 5 x 30	I = (C + D + E)/G
Livestock type	Price (full grown) (€)	Average annual price (€)	Average price reduced to 5 months) (€)	Transport (€)	Ploughing (€)	Daily water consumption (m^3)	Total water consumption (m^3)	Productivity (€/ m^3)
Cattle	261.40	52.28	21.78	-	156.84	0.0392	5.89	30.30
Donkey	89.62	16.29	6.78	29.87	52.28	0.023	3.45	25.78
Sheep	44.81	29.87	12.44	-	-	0.0043	0.645	19.29
Goat	37.34	24.89	10.37	-	-	0.0043	0.645	16.09

4.3.5 Water use efficiency

In order to compute the crop water use efficiency, in addition to the volume of water applied (Vapp) to the crop, the net crop irrigation requirement (volume of water required by plants throughout the evapotranspiration process) (NIR) also is also required.

To compute the net crop irrigation requirement, the CROPWAT model was used. The climatic data was collected from the two nearest meteorological stations (Boromo and Ouagadougou stations) near the reservoirs areas. The crop water use efficiency was computed as:

$$WUeff = \frac{NIR}{Vapp}$$

WUeff: Water Use efficiency

NIR: Net Irrigation requirement

Vapp: Volume of water applied

CHAPTER FIVE

5 RESULTS AND DISCUSSIONS

5.1 Various uses of the selected reservoirs

Information collected through questionnaire, interviews and focus group discussions indicated that all the selected reservoirs were built for livestock and domestic purposes. They were built not by the Burkina Faso government but by an individual (private person).

Plate 5.1: Livestock drinking water from a reservoir at Kagamzinse

It was only some years later that communities served by the reservoirs decided to start using the stored water for farming during the dry season. This may explain the reason for the absence of irrigation canals and the use of pumps by the farmers to draw water from the reservoirs. Farming is done both upstream and downstream.

Plate 5.2: Farmer operating a pump at Kagamzinse

The main crops grown for dry season farming were vegetables such as onion, cabbage, pepper and tomato, and fruits such as pawpaw, banana, citrus and orange. This study takes into account only the vegetables. Table 5.1 below shows the classification of the selected reservoir based on the vegetables grown.

Table 5.1: Classification of the selected reservoirs based on the vegetables grown

Reservoirs \ Crops	Cabbage	Onion	Pepper	Tomato
Konioudou	+	+	+	-
Kierma	+	+	-	+
Pissi	+	+	+	-
Kagamzinse	+	+	-	+
Naba-Zarma	+	+	+	-
Kamboinse	+	+	-	+
Yamtenga	+	+	-	+

\+ Vegetable grown

\- Vegetable not grown

In addition to farming, domestic uses and livestock watering, the stored water in the selected reservoirs was also used for fish farming and brick making.

5.2 Crop water productivities

Table 5.2: Range of yields obtained at the selected reservoirs (t/ha)

Crops	Yield of the seven selected sites (Minimum - Maximum) (t/ha)	FAO yield range (t/ha)
Cabbage	13.5 – 30	40 – 60
Onion	4 – 16	35 – 45
Pepper	3 – 6	15 – 20
Tomato	5 - 20	45 – 65

Table 5.3: Physical water productivity for the selected reservoirs (kg/m^3)

Reservoirs	Cabbage	Onion	Pepper	Tomato
Konioudou	3.08	0.4	0.3	-
Pissi	1.86	0.56	0.28	-
Naba-zarma	4.53	1.82	0.59	-
Kierma	2.63	1.66	-	0.88
Kagamzinse	2.3	1.12	-	2.04
Kamboinse	2.14	0.84	-	1.24
Yamtenga	1.94	2.57	-	1.68
FAO based physical water productivity with WUeff = 100%	7.9	7.2	**2.23**	**5.53**

Table 5.4: Economic water productivity for the selected reservoirs (€/m³)

Reservoirs	Cabbage	Onion	Pepper	Tomato
Konioudou	0.28	0.08	0.08	-
Pissi	0.16	0.1	0.06	-
Naba-zarma	0.4	0.35	0.16	-
Kierma	0.26	0.32	-	0.12
Kagamzinse	0.2	0.22	-	0.28
Kamboinse	0.2	0.16	-	0.16
Yamtenga	0.17	0.5	-	0.22
FAO based economic water productivity with WUeff = 100%	0.7	1.4	0.49	0.74

Table 5.5: Crop water use efficiency (WUeff)for the selected reservoirs (%)

Reservoirs	Cabbage	Onion	Pepper	Tomato
Konioudou	52.16	50.02	69.36	-
Pissi	47.32	45.38	62.92	-
Naba-zarma	85.82	74.7	80.87	-
Kierma	76.86	72.98	-	145.72
Kagamzinse	70.98	68.08	-	83.74
Kamboinse	51.76	49.66	-	60.78
Yamtenga	80.48	78.98	-	119.16

$WUeff = \frac{NIR}{Vapp}$: NIR: Net Irrigation requirement, Vapp: Volume of water applied

The physical and economic crop water productivity (Table 5.3 and Table 5.4) were observed to differ from one crop to another at each site. This may be related to the fact that the crops do not produce the same yield and the amounts of water applied are not the same. Also the crops' market prices are not the same. Considering the crops water use efficiency

(Table 5.5), it was observed that some of the crops may be experiencing water stress through mostly over-irrigation.

Cabbage was observed to have the highest physical water productivity at most reservoirs sites (6 of the 7 selected) (Table 5.3). Even though cabbage water use efficiency was close to the remaining crops' water use efficiency, sometimes was less than the other crops water use efficiency (Table 5.5). Physical water productivity of cabbage was mostly the highest. This may be explained by the fact cabbage may be less sensitive to over-irrigation. Considering Table 5.5 showing crop water use efficiency, it is observed that the crops have been applied more water than they needed and according to literature from FAO (2009), pepper, onion and tomato are described as crops sensitive to both over-irrigation and under-irrigation, but cabbage is described as only sensitive to water deficit but not specifically as sensitive to over-watering. Pepper and onion produce high yield of good quality under controlled irrigation; onion requires frequent supply of water throughout the total growing period; over-watering of onion leads to reduced growth and sometimes causes spreading of diseases such as mildew and white rot; tomato performance is sensitive to the irrigation practices. In order to obtain high yield and good quality, tomato needs a controlled supply of water throughout the growing period; excessive water during the flowering period has been shown to increase flower drop and reduce fruit set; high humidity leads to a greater incidence of pests and diseases and fruit rotting.

Onion was found to have water productivity higher than cabbage at only one site, Yamtenga (Table 5.3). In fact, at that particular reservoir, cabbage yield was the lowest and onion yield was the highest compared to the rest of the reservoirs selected (Table5.6). The reason can be that contrary to onion, cabbage may be experiencing unfavorable agronomic conditions since considering both crops water use efficiency (Table 5.5), cabbage is observed having better water application than onion (ie: cabbage water use efficiency than onion's one). Conditions that may be due to the different farming practices such as fertilizers inputs, types of pesticide used, etc and also the soil type. Cabbage was found to have the highest economic water productivity at four reservoir sites followed by onion, at two reservoir sites and tomato at one reservoir site (Table 5.4), although cabbage was the one having the highest physical water productivity at most selected reservoir sites (6 of the 7 selected). This is due to the fact that tomato and onion have higher selling price than cabbage.

Table 5.6: Crops yield at the selected reservoirs in t/ha

Crops	Konioudou	Pissi	Kierma	Naba-zarma	Kagamzinse	Kamboinse	Yamtenga
Cabbage	30.0	20.0	17.5	27.0	16.5	23.0	13.5
Onion	4.0	6.0	11.25	12.0	8.0	9.0	16.0
Pepper	6.0	3.0	-	5.0	-	-	-
Tomato	-	-	5.0	-	20.0	18.0	12.5

Based on the crops water productivity at all the selected reservoirs (Table 5.3 and Table 5.4), cabbage was found to have the highest physical water productivity, followed by onion, tomato and pepper; and onion was found to have the highest economic water productivity, followed by cabbage, tomato and pepper. Comparing the crops water productivity at the selected reservoirs (Table 5.7) with the one estimated based on FAO range for good yield (Table 4.3), it was observed that productivities at the selected reservoirs are low. This may be explained by the fact that yields obtained at the selected reservoirs are low, below the FAO range (Table 5.2). Over-irrigation may be seen as the reason for low yields and productivities values obtained at the sites. Considering the crop water use efficiency, the amount of water applied to the crops varies with respect to the net crop water requirement. However, tomato water productivity at the selected reservoirs is close to the one obtained in some other African countries (Table 5.8)

Table 5.7: Range of physical and economic water productivity from the selected reservoirs

Productivity	Cabbage	Onion	Pepper	Tomato
PWP (kg/m^3)	1.86 - 4.53	0.4 - 2.57	0.28 - 0.60	0.88 - 2.04
EWP (€/m^3)	0.16 - 0.28	0.08 - 0.35	0.06 - 0.08	0.12 - 0.28

Table 5.8: Tomato productivity compared to productivity obtained in some other African countries

Indicator	Field values	Ethiopia[1]	Ghana[2]	Tanzania[1]
Tomato PWP (kg/m^3)	0.88 – 2.04	1.54	0.86 – 1.72	1.47 – 2.4

Source: [1]: Mamba (2007), [2]: Productivity computed based on theMinistry of Food and Agriculture (Ghana) averages range (assuming 70% water use efficiency).

5.3 Physical water productivity and water use efficiency

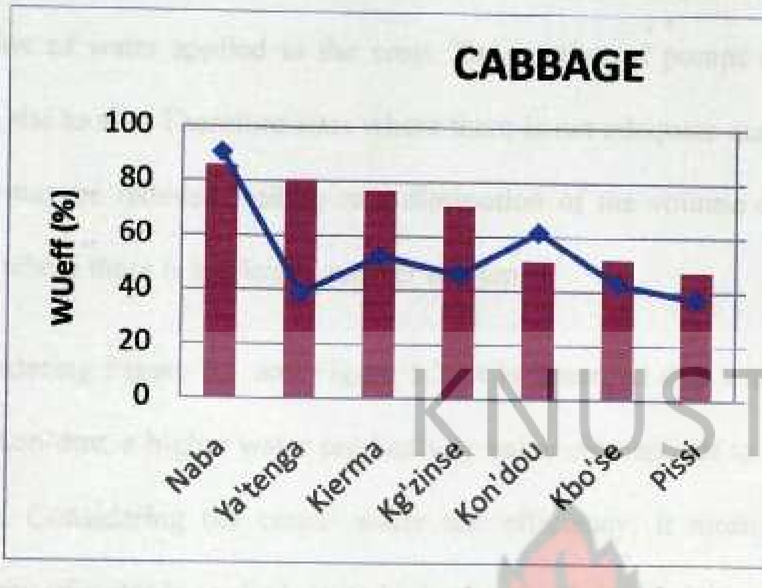

Figure 5.1: Cabbage physical water productivity and water use efficiency for the selected reservoirs

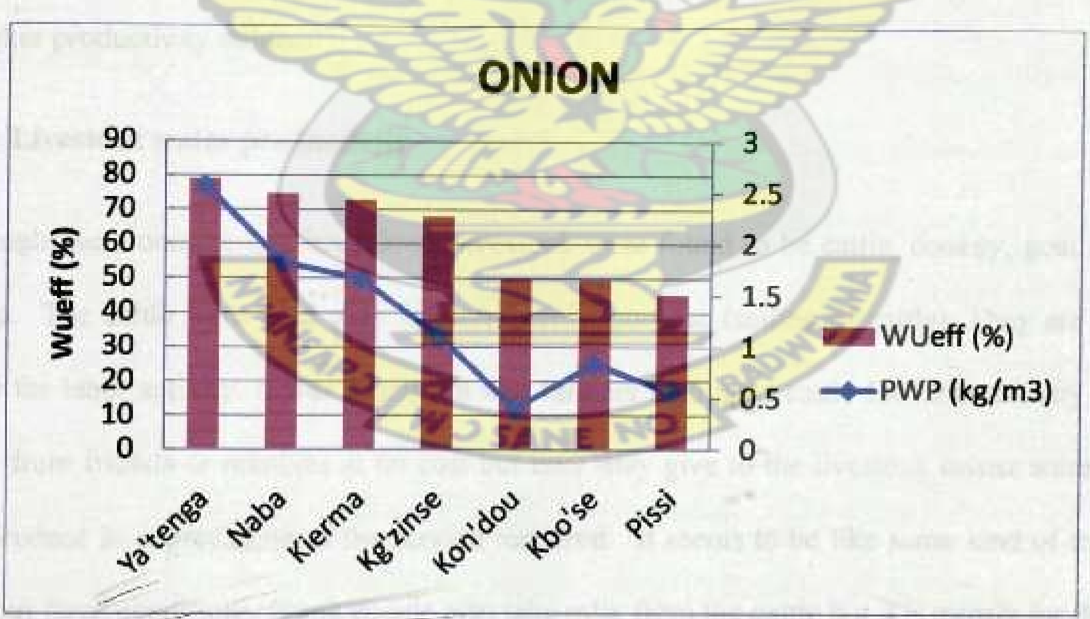

Figure 5.2: Onion physical water productivity and water use efficiency for the selected reservoirs

For each crop considered, water productivity differs from site to site. The difference in physical water productivity observed from site to site may be related to the difference in the volume of water applied to the crop. The number of pumps available for farmers differs from site to site. Therefore sites where there is not adequate number of pumps, the pumping time may be reduced leading to a diminution of the volume of water applied compare to sites where there is sufficient number of pumps.

Considering Figure 5.1 and Figure 5.2, it is observed that with the exception of Ya'tenga and Kon'dou, a higher water productivity value corresponds to a better water use efficiency value. Considering the crops' water use efficiency, it means that when quite adequate quantity of water is applied, quite higher productivity is obtained. This may be explained by the fact that application of adequate quantity of water may lead to higher yield. Considering the formula used for the computation the productivity, higher yield with less water will give a higher productivity value.

5.4 Livestock water productivity

Through questionnaire and interviews, livestock were found to be cattle, donkey, goat and sheep. The cattle were bred only for commercial purpose (selling of cattle). They are not hired for labor activity. It was found out that farmers who need cattle for labor activity get them from friends or relatives at no cost but later may give to the livestock owner some of the produce in appreciation of the service rendered. It seems to be like some kind of trade without fixed conditions. Some people also take milk from the cattle but it is mostly for their own consumption and it is not frequent. To compute cattle water productivity, this study takes into account only the revenue obtained from selling cattle and also the price farmers will be willing to pay for cattle if the cattle used for labor activity was not free of charge. Because of the great number of reservoirs in the area and also of the feeding of the cattle, cattle travel a lot and it was difficult to attribute cattle productivity for a particular reservoir since it was not possible to point exactly from which reservoir they drink. Also, cattle are sign of prestige and wealth; more cattle one has more respect accorded him.

Concerning donkeys, they are used for only transportation. Goats and sheep are bred just for selling; goats and sheep do not provide any other services. Cattle, donkey, goat and sheep water productivities were found to be respectively 30.33€/m^3, 25.78 €/m^3, 16.09 €/m^3 and 19.29 €/m^3. As it is observed, even though sheep and goat have the same water consumption, their water productivities are not the same. This may be explained by the fact that sheep has a higher sale price than goat, due to its bigger size compared to goat and to the fact that it is more preferred than goat by the Muslim community.

Livestock water productivities in this study show significant differences compare to livestock water productivities in Upper East Region of Ghana. Higher productivity values for cattle and donkey in Ghana compare to the results of this study are due to the higher values placed in using cattle and donkey for ploughing in Ghana than in Burkina Faso (more than two times the value placed in using livestock for ploughing in Burkina Faso). Also transportation service provided by donkey in Ghana costs more than in Burkina Faso (about three times the cost of using donkey for transportation in Burkina Faso). This due to the fact that in the study area, farmers are mostly the one using donkey for transportation and most of them have their own donkey. Goat and sheep productivity in Ghana is the same, while in Burkina Faso it is higher and differs. This is due to the fact that goat and sheep show same selling price in Ghana while in Burkina Faso, Sheep selling is higher than the selling price of goat. However, livestock water productivities are higher than crops water productivity in both studies.

CHAPTER SIX

6.1 Conclusions

- Crop water productivity at the selected reservoirs is low compare to the FAO range, but close to productivity values obtained in some other African counties.
- Considering livestock and crops, it is more productive to invest water in livestock than in crops, however an optimal benefit from using both should be explored
- Among crops, it is physically more productive to use water to grow cabbage.
- Among livestock, it is more productive to use water for cattle
- Crop water use efficiency values show that the crops studied may be experiencing water logging. There may be then an opportunity to improve crops water productivity through controlled application of water.

6.2 Recommendations

Considering the outputs of this study, I recommend that:

- Subsequent research should
  - Take into consideration factors such as labour, soil fertility, types of fertilizer used, energy, etc.
  - Use optimization to determine the most efficient water allocation.
- Since there is an opportunity to enhance crop water productivity through controlled water application, extensions officers should enhance farmers' knowledge about the amount of water the crops need and ways to apply close to the exact quantity.

REFERENCES

Abdou-Sabam, S. (2006). Water Resources Management in Burkina Faso: A case study on the potential of small dams. Water aid report.

Allen, R. G., Pereira, L. S., Raes, D. and Smith, M. (1998). Crop Evapotranspiration: Guidelines for Computing Crop Water Requirement. FAO Irrigation and Drainage Paper 56. FAO Rome.

Amare, H., Peden, D. and Tadasse, G. (Undated). Livestock Water Productivity: concepts and Practices. Experiences from mixed farming system in east African highlands. International Livestock Research Institute (ILRI).

Amisigo, B. (2005). Modeling River Flow in the Volta Basin of West Africa: A Date Driven Framework. Ecology and Development Series No. 34. Curvillier Verlog Gottingen

Andah, E., van de Giesen, N. and Biney, C. A. (2003). Water Climate, Food and Environment in the Volta Basin. Adaptation Strategies to Changing Environment. Contribution to the ADAPT Project.

Annan, K. (2002). UN Secretary General Kofi Annan's Message on World Food Day. New York, USA.

Benneh, G., Agyepong, G. T. and Allotey, J.A. (1997). Land Degradation in Ghana. Food Production and Rural Development Division. Commonwealth Secretariat, Marlborough House, Pall Mall. London

Central Intelligence Agency (CIA). (2001). Burkina Faso. The 2008 World Factbook.

Clanet, J. C., Andoch, W. and Lemoalle, J. (Undated). Water Productivity Estimation in the Volta Basin, West Africa. Institut de Recherche pour le Developpement (IRD), UMRG-EAU, Water Research Institute, Accra, Ghana.

Clarke, D., Smith, M. and El-askari, K. (2000). CropWat 4.0 for Windows 4.3. University of Southampton, United Kingdom.

Clemmens,A. J and Burt, C. M. (1997). Accuracy of Irrigation Efficiency Estimates. Journal of Irrigation and Drainage Engineering. 123: 443 – 453.

Cooks, S., Gichuki, F. and Turral, H. (2006). Agricultural Water Productivity: Issues, Concepts and Approaches. Basin Focal Project Working paper No.1, CGIAR Challenge Program Water for Food, Nairobi, Kenya.

Cooks, S., Gichuki, F. and Turral, H. (2006). Agricultural Water Productivity: Estimation at Plot, Farm and Basin Scale. Basin Focal Project Working paper No2, CGIAR Challenge Program Water for Food.

Inocencio, A., Barker, R. and Dawe, D. (2003). Economics of Water Productivity in Managing Water for Agriculture. International Water Management Institute, CAB International, Colombo, Sri Lanka.

Keller, A., Sakthivadivel, R. and Seckler, D. (2000). Water Scarcity and the Role of Storage in Development. Research Report 39. Colombo, Sri Lanka, IWMI.

Lemoalle, J. (2006). Challenge Program on Water and Food Basin Focal Projects: Volta Proposal. Project Proposal. Institut de Recherche pour le Developpement (IRD), Paris, France.

Mamba, G. C. (2007). Quantifying Total Water Productivity for Multiple Use Small Reservoirs in Mzingwame Catchment, Zimbabwe. MSc Thesis, University of Zimbabwe.

Manzungu, E. (2002). The Processes and Dynamics of Catchment Management in Zimbabwe. Proceedings of a Workshop Held at Monomotapa Hotel, Harare, Zimbabwe, 24 June 2002. Save Africa Trust Publication, Harare.

Mathieu, O., Leopold, S. and Youssouf, D. (Undated). Economic Impact Assessment of Climate Change on Agriculture in Burkina Faso: A Ricardian Approach. Centre for Environmental Economics and policy in Africa (CEEPA) publication.

Mdemu, M. V. (2008). Water Productivity in Medium and Small Reservoirs in the Upper East region of Ghana. PhD Thesis, University of Bonn, Germany.

Molden, D., Habib, Z. and Sakthivadivel, R. (2001). Basin level Use and Productivity of Water: Examples from South Asia: Research Report 49, Colombo, Sri Lanka. International Water Management Institute.

Peden, D. and Tadasse, G. (2003). Effective Management of Water and Livestock Resource for Community Based Irrigation in Ethiopia. International Livestock research Institute (ILRI), Ethiopia.

Oguntunde, P. G. (2004). Evapotranspiration and Complementarity relations in the Water Balance of the Volta Basin: Field Measurement and GIS – Based Regional Estimates. Ecology and Development series No. 22. ZEF Bonn. Curvillier Verlag Gottingen.

Ouedraogo, M., Leopold, S. and Dembele, Y. (2006). Economics Impact Assessment of Climate on Agriculture in Burkina Faso: A Ricardian Approach. CEEPA Publications.

Oweis, T. and Hachum, A. (2003). Improving Water Productivity in the Dry Areas of West Africa and North Africa. In: Kijne, W. I., Barker, R. and Molden, D. (Editors). Water Productivity in Agriculture: Limits and Opportunities for Improvements, pp. 179 – 197. CABI Wallongford.

Rijsberman, F. (2001). Can the CGIAR Solve the World Water Crisis? Paper Presented at the CGIAR Mid – Term meeting in Durban, South Africa. p. 7.

Rodgers, C., van de Giesen, N., Laube, W. and Youkhana, E. (2007). The GLOWA VOLTA Project. A Framework for Water Resources Decision Making and Scientific Capacity Building in a Transnational West African Basin. In: Craswell, M., Bonell, D., Bossio, S. and van de Giesen, N. (Editors). Integrated Assessment of Water resources and Global Change (A North – South Analysis). Springer, pp: 295 – 313.

Rosegrant, M.W., Cai, X. and Cline, S. A. (2002). Global Water Outbook to 2020. Averting an Impending crisis. A 2020 Vision for Food, Agriculture and the Environment Initiative. International Food Policy Research Institute/International Water management Institute, Washington Dc, USA/Colombo, Sri Lanka.

Rusere, S. (2005). An Assessment of Multiple Uses of Small Dams, Water Usage and Productivity in the Limpopo Basin. BSc Thesis, University of Zimbabwe.

Senzanje, A. and Chimbari, M. (2002). Inventory of Small Dams in Zimbabwe. IWMI, Colombo, Sri Lanka.

Sharma, B. R. (2006). Crop Water Requirements and Water Productivity: Concepts and Practices. College of Agricultural Engineering, Punjab Agricultural University, Ludhiana

Sivakumar, M. V. K. and Some, L. (1994). Analyse de la Longueur de la Saison Culturale en Fonction de la Date du Debut des Pluies au Burkina Faso. Compte Rendu des Travaux No. 1. INERA Burkina Faso. ICRISAT Niger.

Wagner, S., Hunstmann, H and Bardossy, A. (2006). Model Based distributed Water BalanceMonitoring of the White Volta Catchment in West Africa through Coupled meteorological hydrological Simulations. Advances in Geosciences., 9, 39 – 44, 2006.

Williardson, I. S., Allen, R.G. and Frederikson, H.D. (1994). Universal Fractions and Elimination of Irrigation Efficiencies. Paper presented at the 13th technical Conference, USCID, Denver, Colorado, Duplicated.

World Meteorological Organization (WMO, 2001). Guide to Hydrological Practices, WMO, Geneva, Switzerland.

Zinash, S., Azage, T. and Getnet, T. T. (2002). Improving the Water productivity of Livestock. An Opportunity for Poverty Reduction. In: McCornick, P. G., Kamara, A. B and Tadasse, G. (Editors). Integrated Water and Land Management Research and Capacity Building priorities for Ethiopia. Proceedings of a MoWR/EARO/IWMI/ILRI International Workshop Held at ILRI, Addis Ababa, Ethiopia.