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Research article

Cost-Effective Perspective and Scenario Development on Economic Optimization for Multiple-Use Dry-Season Water Resource Management

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Abstract

Water productivity (WP) as a measure of performance of the physical quantity or economic value derived from the use of a given quantity of water is critical in assessing the value of water. Multiple water-use systems are considered to be more efficient as they embrace the value of water from several uses that may not have been considered during planning and design of water reservoirs, but subsequently incorporated in current planning and performance assessments, for which the Golinga Irrigation Dam is no exception. Several water use sub-sectors were identified, analyzed and grouped into three main sectors. Water used by the brick sub-sector was estimated by the number (111) of bricks produced per day, the quantity ($0.5m^3$) of water used per (3) days of work in a week for the total number (20) of weeks in the production period. Forty five (45) brick workers were involved. Three Fishermen were monitored during fish catch periods and their catches weighed. Fish prices were obtained from fishermen and verified from the Tamale market. Livestock counts were unobtrusively done at the dam site. Irrigation water losses were measured. Women who fetched water from the dam, both in the early hours of the morning and late afternoons and on specific days, for domestic purposes were counted and their container sizes measured for a period of one week. The total number of inhabitants at the Golinga area was 4074, based on the 2000 Ghana Statistical Survey and a field survey conducted in 2010. A per capita daily water consumption was based of 20.5 liter for rural un-piped systems (Water Net, 2003). Crop water application was found to be far beyond plant needs by close to 50% and hence should be reduced to the barest minimum in order to increase water use efficiency which makes water use productive. The Environment sector consumed the largest share of the reservoir yield (76.8%) followed by Agriculture (22.3%) and finally, Domestic/ Industry (0.9%) for 2009 – 2010 dry season period. This gave an overall estimated total income of about US$ 3,730,560 to users. However, after re-allocating the available water through 4 different scenario, it was possible to increase income from US$ 4,704,864 (26%) to US$ 11,739,392 (196%) when 10% of water from the agriculture sub sector, is allocated to the livestock sub-sector only. The study suggests that WP in the study area is low due to inappropriate allocation of scarce water resources to uses, and that a potential for improvement exists within the reach of the management agencies (IDA, MoFA, Reservoir management committee) of reservoir water resources and the farmers.

Keywords: Water productivity, Physical water productivity, Economic water productivity, Multiple-use, Scarce water resources, Water Use Efficiency, water resources management.

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1. Introduction

Water resources management has taken a prominent place in one of the most vital research fields for worldwide researchers. UNEP (2002, 2004) has confined its attention in this direction. It is estimated that two-thirds of the world's population will live in water stressed regions by 2025 (UNEP, 2002), with water stress defined as demand over supply with growing conflict between users, declining standards of reliability and service, increased potential for harvest failures and food insecurity, for more details we refer Falkenmark and widstrand [10]. In the world, African countries are facing problems of water resources. It has been predicted that in Africa alone, by 2025, almost twenty five nations are projected to experience stress with regards to water resources (UNEP, 2002). However, Hunter [16] focused attention to explore household strategies in the face of resource scarcity in Coastal Ghana and observed that in many developing countries, women and children spend several hours daily in the collection of scarce natural resources such as water. This notwithstanding, the link between these household resource strategies and stakeholder perceptions of development priorities remain unexplored. For example, in Colombia, many water schemes have been developed with the purpose of domestic supply and water for processing of coffee beans, while Pig rearing, a women activity is considered a waste, we refer to Butterworth *et al.* [3]. Moreover, Van Koppen *et al.* [50] confined in their studies that in Zimbabwe also, water points were designed to meet water demands for domestic uses and Cattle watering but not for backyard gardening, which is a responsibility of women. The rural poor and particularly women in South Africa, use "domestic water supplies for a wide range of productive activities (Perez de Mendiguren Castresana [37]). Although sub-Saharan Africa's agricultural water withdrawals remains relatively limited (Dembele *et al.* [8]), irrigation growth will have to contend with increased competition from other sectors such as domestic and industrial uses. Meanwhile, there has been significant scope of improvement in water productivity in recent times. Thus, about 15,000 m3 of water is required to irrigate 1 hectare of rice in the Sahel region and this corresponds to the needs of 450 heads of cattle over 3 years or to those of 100 rural families for 4 years, or 100 urban families for 2 years (Carrunthers and Clark [4]). In view of Hanjra, *et al.*[13] and Molden *et al.* [30] the agricultural water productivity cannot be decoupled from rural poverty and its improvement will enable more people to benefit from a finitely shared water resources (Cooks *et al.* [6]). Hence, there is utmost need for a crop water production function for the improvement of WUE and effective allocation of water resources in a region (Zhang and Oweis [54]). The relationship between crop growth or yield and water use have been a major focus of agricultural research in the arid and semi-arid regions as reviewed by some noteworthy researchers Hanks [14], Vaux and Pruitt [51] and Howell [15]. Consequently, a major research challenge is to devise cropping systems that maximize water use efficiency (WUE).

The relevant facts reveal that the greatest limitation to growth was the adequate and judicious supply of water and not the soil moisture storage potential (Pala *et al.* [33]). Ward and Michelsen [52] and Wichelns [53] succeeded to point out that conserving water through more efficient use and improving water productivity is one strategy to

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addressing future food security and water scarcity issues. The contribution of small scale water resources to sustainable rural development includes for example securing food, efficient use of water, farm materials and other resources, creating wealth, diversifying livelihoods, generating rural employment and income, fostering social harmony and empowering women. While the aforementioned is acknowledged by stakeholders in the water sector, there hasn't been a systematic and scientific approach to measuring multiple – use water productivity with the Golinga irrigation dam. Several previous researchers e.g. (Chambers *et al.* [5], Hussain [17] and Van Koppen [50]) experienced from their studies in this direction that the concentration of some developed irrigation and land resources in few areas are well documented but the various ways to better target services are hardly mainstreamed. In water-scarce environments such as in the Northern Region of Ghana, sectoral water use and allocation should be based on the economic, livelihood or biophysical outputs derived from the use of a unit of water (Mdemu [26]). The application and acceptance of the concept of water productivity will ensure effective use of water. Therefore, this study seeks to using scientific methods to estimate the dry season multiple-use WP of the Golinga Irrigation Dam in the Northern Region of Ghana, with respect to Domestic/Industrial, Agricultural production and Environment sectors. This will also re-allocate scarce water resource through scientific scenario building, to the aforementioned uses for optimum socio-economic benefit for all stakeholders. In this connection, Maurya *et al.* [24-25] and Van Kopen *et al.* [49] also contributed their research.

2. Learning Materials and Methodologies

2.1 Statistical Data Source

The data for the present study is based on the *Golinga* dam which serves *Galinkpeagu*, *Gbulahagu* and the *Golinga* communities in the *Tolon-Kumbungu* district of the Northern Region. The *Golinga* dam is one of the numerous small/medium multiple-use reservoirs in the region and it is located at latitude 9^0 34' 15.75"N and longitude 1^0 01' 21.13"W. The dam was constructed between 1971 and 1974. It was redeveloped in 1980 by the government of Ghana for the purposes of irrigation farming. The reservoir has a catchment area of 16,500 km^2 and a capacity of 12,300,000 m^3 (Gordon [11]). We remark here that such data can also be collected for future research in the field from other dams located in India, China and other countries.

2.2 Climate Vegetation, Geology and Soil

The climate of the region is influenced by the movement of two types of air masses: the North East (NE) and South west (S W) trade winds, which control the climate of the West African sub-region. The harmattan, or North East (NE) trade winds, originate from the Sahara desert and are characterised by dry and particle-laden air masses. The SW trade winds (monsoon) carrying moist air from the Gulf of Guinea brings rain upon converging with the NE trade winds. Movement of the Inter-Tropical Convergence Zone (ITCZ), i.e. the boundary between the two air masses, influences the climate of the savannah region. There are two main seasons (rainy and dry seasons). The wet season is between May and October, with an average annual rainfall of 759 mm to 1068 mm.

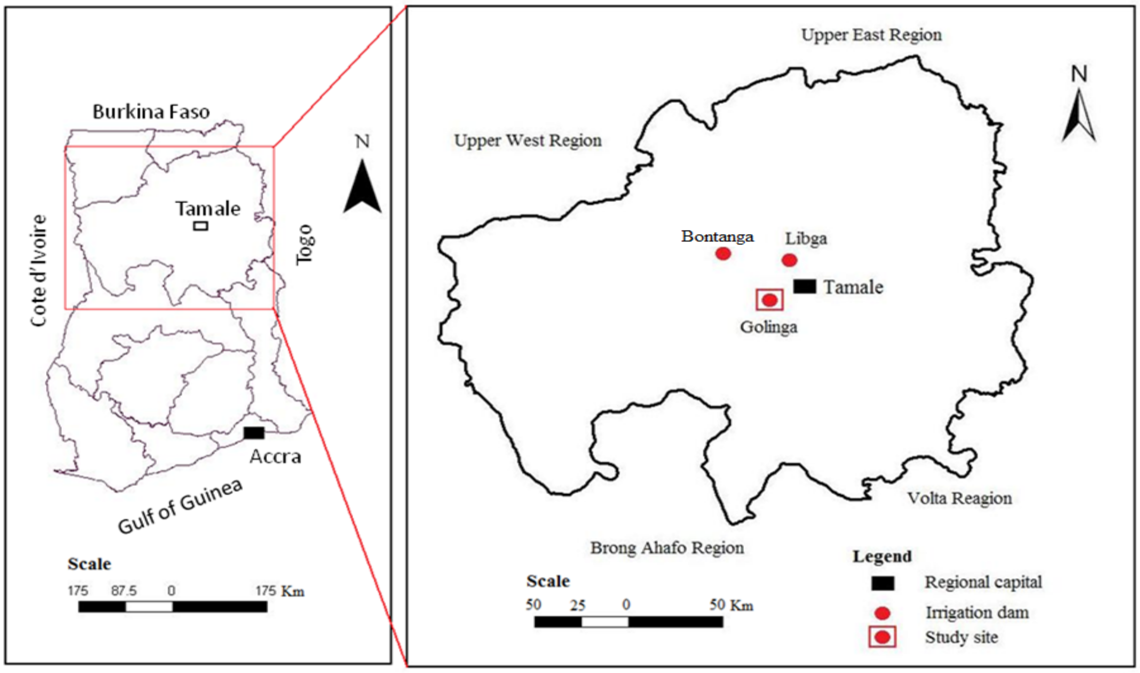

Figure 1: A map of the Northern Region and showing the location of Golinga Dam.

Temperatures do vary between 14° C at night and 40°C during the day. The dry season is from November to March. The maximum temperature is attained at the end of the dry season with the minimum in December to January. The vegetation is Guinea Savannah and consists predominantly of a cluster of drought-resistant trees such as Baobabs (*Adansonia digitata*) and Acacias such as (*Casia albida*).

2.3 Water Resource Development, Poverty Reduction and Livelihood Sustenance

Water accessibility considers water as a commodity and ensures that households have full or firm control of the available water. Easy accessibility, reliability and constant availability of adequate safe water to satisfy basic human needs ensure water security (Ariyabandu and De [1]. This implies that households are able to obtain the required quantity of suitable quality water for basic needs and other economic activities (Ratnaweera [39]).

In an environment such as the study area, water is a scarce resource and has its multiple uses. In the northern regions of Ghana, water is used for crop production, aquaculture, livestock, industry, "*pito*" brewing, food processing and can improve water productivity to reduce poverty and enhance people's livelihood. Therefore, water management must have a clear and objective approach so that people /communities will derive maximum benefits from its use. For a community, the idea is to generate more benefits and incomes, decrease vulnerability against any distress situation with more diversified livelihood strategies, reduce poverty, equitable and environmentally sustainable water allocation and protection of people's basic multiple needs and services makes it necessary to develop a workable and acceptable platform for resource allocation in distress times. There is a greater need to improve water management in reservoirs located in such environments.

Considering the general increase in water scarcity, increasing the production per unit of water has been identified as one of the world's most serious problems requiring urgent attention. Improving water productivity (WP), is an important strategy for addressing future water scarcity, which is driven particularly by population growth and potential changes in climate and land use (Mdemu [26]). An increase of WP in agriculture by 40% may reduce the amount of additional freshwater withdrawals needed to feed the world's growing population to zero (Molden *et al.* [28]). How, when, and where such a breakthrough could be realized is currently uncertain. While greater water productivity in the aggregate will almost certainly be necessary to reduce the negative impacts of future water scarcity, it is important to keep in mind that for any specific technology, project, or policy, higher water productivity does not necessarily result in increased benefits to society (Barker *et al.* [2]). For example, some interventions may raise water productivity only at the expense of using other scarce resources (e.g. land, labour, capital), with the net effect being a reduction in economic efficiency. This is not to say that increases in water productivity must come without using other resources, only that those other resources must also have a value attached to them. However, it is clear that WP improvement is a critical condition for sustained human development (UNDP, 2006). Estimates of WP have two basic uses (Cooks *et al*. [7]): firstly, as a diagnostic tool to identifying the level of water-use efficiency of a system under study and secondly, to provide insight into the opportunities for better water management towards increased WP for the scale under consideration. Increased competition for water between agriculture and other sectors such as the environment and urban water demand is one of the expected consequences of water scarcity (Tropp *et al*. [45]). While many sectors may experience water stress, irrigated agriculture, which accounts for about 80% of blue water withdrawals in developing countries (UNDP, 2006), will face the real problem of water scarcity. Water stress is a situation occurring when water demand exceeds available supply during a certain period (UNEP, 2004), and blue water is the combination of surface and renewable groundwater resources (Savenije [43]).

Furthermore, in many other researches (e.g. Rijsberman and Manning [41], Qadir *et al*. [38] and UNDP, 2006) the inability of irrigated agriculture to compete economically with other sectors for water, further compounds the problem of water scarcity in irrigated agriculture. The estimated value of water for irrigated agriculture is typically below the value of water in urban sectors. Urban demands thus out-compete irrigation demand, and water is reallocated from irrigation to satisfy the rapidly growing urban and industrial demand in developing countries. Although Ghana, like many sub-Saharan African (SSA) countries is projected to experience economic rather than physical water scarcity by 2025 (IWMI, 2000), geographically disadvantaged settings within Ghana such as the Northern Regions often face severe physical water scarcity far beyond the figure suggested by national average per capita water resources. A country with adequate water resources but lacking capacity to develop water infrastructure to supply water is referred to as economically water scarce, whereas a country with water resources insufficient to support its population experiences physical water scarcity (IWMI, 2000). Most water-scarce regions coincide with regions where most of the poor and food-insecure people live (Cooks *et al*. [7]). The Golinga area is a case in point. Improving water productivity (WP), a measure of performance generally defined as the physical quantity or economic value derived from the use of a given quantity of water (Molden *et al.* [29]), is one important strategy towards confronting future water scarcity. Increasing WP to obtain higher output for each drop of water used can play a key role in mitigating water scarcity, for further details we refer (Molden *et al.* [28]; UNDP, 2006).

2.4. Total Water Productivity

Water productivity was considered from a number of perspectives: Physical water productivity in agriculture refers to obtaining more crop products from the same amount of water; while, in socio-economic terms, water productivity refers to obtaining more value per unit of water used (Molden *et al.* [28]). The water productivity concept acknowledges the importance of competing uses of water, by focusing on water related activities in a community/catchment. Water related activities include demands for agriculture, non-agricultural water, human demand, water for maintaining ecosystem services. Physical water productivity is simple but useful only for single product. Monetary (economic) indicators are useful where products or multiple uses of water are to be analysed (Hussain *et al.* [18]). Total water productivity enables prioritisation of water use for the attainment of maximum societal benefits. Prioritisation of water use is necessary especially in arid and semi-arid regions such as the northern regions of Ghana, where water is not adequately available. Molden *et al.* [28] proposed in their research work that following are three paths of increasing water productivity per unit of utilizable water resources;

- Developing and consuming more primary water by increasing the developed storage and diversion facilities,
- Depleting more of the developed primary water supply for beneficial purposes by increasing water savings,
- Producing more output per unit of water depleted by increasing unit water productivity

2.5 Comparing Rainfall, Runoff and Evaporation

A 30 year monthly rainfall data collected from the Tamale meteorological station for the period 1980 to 2009 indicates a low rainfall regime for November to April. But with an average annual rainfall of 1068.135mm, mean annual runoff of 212.22mm and a mean annual evaporation of 1776.82mm. Comparing the three parameters indicate a very high evaporation rate representing a minimum deficit of about 700mm. Hence, the indispensable nature of multiple-use small reservoirs to store the runoff generated. Well formulated water re-allocation should, therefore, enable productive utilization of the available water in the reservoir before occurrence of significant evaporative losses.

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2.6 Statistical Estimation of Water Productivities

2.6.1 Bricks Water Productivity

Average masses (15.8 kg) per brick of 45 bricks at three randomly selected locations were weighed with an electronic scale. Six (6) bricks were moulded with 0.027m^3 of water. From these values, quantity of water used per brick and mass of each brick was estimated. The aforementioned activities were carried out /monitored in December, January and February. Water productivity was expressed in terms of physical (kg/m^3) or monetary (USD/m^3). Monetary water productivity for bricks is more useful than physical water productivity (Munamati et al. [31]). Analysis of questionnaire reveals that about 45 brick moulders (2009/2010) existed in the Golinga area and moulding on the average, three (3) days per week. Seventy five percent (75%) of the brick moulding was done in January, with 25% in December and February. Bricks had the highest physical WP of 3500 Kg/m^3 but of the third highest monetary water productivity of US$ 3.80/m^3 (Table 1). Respondents/brick moulders (81%) indicated that labour to draw water for brick making is a major constraint to their work, compared to waterborne diseases infection (5%) and the issue of proximity to water (11%). Most reservoir management committees were ensuring that brick making was controlled because of environmental concerns such as erosion and siltation of reservoirs.

2.6.2 Crops Water Productivity (CWP)

Crop water productivity is defined either in physical or monetary terms as the ratio of the product (usually measured in kg) over the amount of water depleted. It is usually limited to evapo-transpiration, measured in m^3 (Mdemu [26]). Crop water productivity for applied water was estimated for commonly grown crops in the study area. Rainwater was not included. Data for calculating crop water productivity were obtained through interviews and physical measurements. Examples of data obtained were; amount of water applied to a crop, crop yield, income from yield and additional income from bye-products of the crop. Physical water productivity was estimated as the total yield divided by the amount of water applied, estimated from the volume of water applied per bed, the number of beds, and the frequency of watering (Lovel [22]). The crop water productivity was worked out by dividing the crop yield by total water applied. Farmers had several reasons for cultivating particular crops. These are, economic, cultural, agronomic etc. But for reasons of economic and livelihood sustenance, some objective approaches to water productivity concept needed to be carried out. Under the WP approach, all the crops grown in an area were subjected to the analysis and the derived benefits realised. In this case, farmers in the community weighed the options, to derive the maximum benefits for all actions taken. The crops water productivity (CWP) is given by following equation in (2.6.1):

$$\text{CWP} = \frac{\text{yield (kg)}}{\text{total water used } (m^3)} = \frac{\text{gross income(GHc)}}{\text{total water used } (m^3)} \qquad (2.6.1)$$

Vegetables such as leafy vegetables ''Bra /Ayoyo'' (*Amaranthus spp*), okra (*Hibiscus esculentus)* garden eggs (*Lycopersicum spp*), pepper (*Capsicum spp*) and onion (*Alliums spp*) were the most cultivated crops for the 2009/2010 irrigation season. Sixty five (65%) percent of farmers cultivated leafy vegetables, 17% okra, 8% garden eggs, 6% pepper, 2% onion, 1% cowpea and 1% maize . The Leafy vegetable, okra, pepper, and onion were studied for their individual water productivities. Four farmers each per the aforementioned crops were monitored for crop production data. The monetary WP of these crops showed that leafy vegetables (Ayoyo/Bra) had the highest productivity of about US$1.86 followed by pepper (US$1.30), okra (US$0.57) and onion (US$0.29) as presented in Table 2. Meanwhile, their physical WP were 6.50 kg/m^3, 1.81 kg/m^3, 0.48 kg/m^3 and 2.26 kg/m^3 respectively.

In order to serve societal values, low water productive crops can be grown during the rainy season when water resources are relatively abundant. Alternatively, they may also be imported from other parts of the country by using part of the income realised from the sale of the high value products within the concept of virtual water.

2.6.3 Domestic Water-Use Productivity (DWP)

Productivity for domestic water use was determined by halving the cost of treated water per cubic meter (Kachapila [20]) as supplied and charged (0.46 US$ /m^3) by the potable water providers, Ghana Water Company Limited (GWCL) and AquaVittins Rund Limited (AVRL)**.** Domestic water productivity was estimated from measuring the quantity of water fetched from the reservoir by a random sample of 30 women at Golinga reservoir on three different days of the week both in the morning and evenings (at the weekend, on a market day and a typical school day) while using a calibrated bucket to measure their containers. A corroboration of this is done by the use of questionnaire to know the quantity of water-use per household on a daily bases. Two hundred and fifty-six (256) households used the reservoir and each household was estimated to comprise six persons. The formulation of the re-distribution strategy, however, used 25 litres per capita-day of reservoir water as the upper threshold for rural un-piped water supply demand. Hence, for a dry season period of 5 months (151 days), a population of 4074 will consume an approximate quantity of 15,000m^3 of water. Productivity was expressed in US\$/m^3. Domestic water use plays many functions in the livelihood of a society. These functions include food preparation, sanitation and hygiene, drinking and laundry. Domestic economic WP was valued at US$ 0.23 (Table 1). The study did not assess the multiplier effect of domestic water use beyond the supply cost.

2.6.4 Fish Water Productivity (FWP)

Fish water productivity data was obtained on average fish catch per day for the wet and dry seasons, respectively. Data was verified against trial fish catches. The average weight and number of fish for each bundle was recorded, and the average price of fish bundle was obtained through interviews at the Tamale market on the 27th July, 2010. The average weight of fish caught per fisherman per day in the dry and wet season was 9.92 kg and 12.40 kg, respectively. Fish were sold at US$2.10 per bowl (Olonka) of 4.96 kg. Water depleted from fisheries was determined from the total volume of water that evaporates from the reservoir during the wet and dry seasons (Lemoalle [21]). Both physical or monetary water productivities were estimated. Fishery water requirement is equal to dead storage plus evaporation loss (Lemoalle [21]). Quantity of water maintained in the fish pond as dead storage was determined using the size of the Dam and height of water column at the end of the dry season period (February). The quantity of water added to the Dam at particular interval to maintain or increase the dead storage can be accounted for as evaporation loss from the Dam (Munamati et al. [31]). The fishery water productivity (FWP) is given by following equation in (2.6.2):

$$\text{Fishery Water Productivity} = \frac{\text{Total fish yield (kg)}}{\text{Total water used (m}^3\text{)}}$$

(2.6.2)

Fish water productivity was determined as follows:

- Two fishermen were hired to catch fish continuously around the reservoir from 05:00 to 07:00 hours GMT, while another was monitored unobtrusively in order to determine the catch per unit effort (CUE) for comparison with data recorded through interviews. Most of the fishermen used Canoe and Nets to catch fish.
- The catch was weighed on an electronic scale and the number of fish types recorded. The average weights of fish caught per fisherman per day in the dry and wet season were determined and the sale of fish per bowl or unit weight is recorded.
- The most common fish species caught were Tilapia (*Tilapia guinasana*). It comprises of about 58% of the entire composition of fish species harvested from the dam.
- Others include Catfish (Black Bullhead) (*Ictaurus ameiurus melas*) and Pacific Herrings which were recorded as 42%.

2.6.5 Livestock Water Productivity (LWP)

Livestock water productivity is defined as the ratio of the sum of the net benefits derived from the volume of water depleted to produce livestock products and services (Peden *et al* [36]) and can be expressed as monetary water productivity. Livestock water productivity (LWP) was estimated from annual average sales of livestock products and services eg., livestock sale, dry and wet season milk production, equivalent nitrogen content in dry matter manure and traction/drought power for transport and ploughing. Livestock data was obtained through livestock traffic count, verified with a dip-tank livestock records from the Ministry of Food and Agriculture, Tolon, and also, with the aid of questionnaires. The total water used for animal rearing includes water for drinking, water for washing animals and water for the production of fodder/forage (Pallas [34]). The estimated water productivity for livestock (cattle, goat, sheep and donkeys) is given by equation (2.6.3) in view of Peden and Tadesse [35] as following:

$$LWP = \frac{Milk\ yield\ (litres)\ or\ Meat\ (Kg)}{Total\ water\ used\ (m^3)} = \frac{Gross\ return\ (GHc)}{Total\ water\ used\ (m^3)} = \frac{\sum(O+S)}{W_d} \quad (2.6.3)$$

Where; O – Livestock output cost, S – Livestock service cost, W_d – Depleted water.

Livestock output could be total milk yield (Litres) per animal per lactation period and or meat. On draught power, cattle (oxen) were allowed to work three days in a week. Oxen worked on the average of 5 hours per week for about a month during land preparation. Calculation of voluntary water requirements was done using long-term mean monthly temperature data from the Ghana Meteorological Agency, Tamale, as proposed by the FAO, suggesting a variation between species and breeds, feed intake, quality of feed and air and water temperature (FAO, 1986).

Livestock count per week at the dam site showed that an average of 16, 11 and 6, cattle, sheep and goat respectively visited the reservoir within a period of an hour in the mornings, while 18, 23 and 8 cattle sheep and goat respectively visit the reservoir within an hour in the late afternoons. Thus, greater numbers were recorded late in the afternoons probably due to an increase in temperature and dry feed intake. Respondents indicated that about 24% of the cows were milked. Also, forty two percent (42%) of the 24% were milked in the dry season, while 58% were milked in the wet season. During the dry and wet seasons, a cow produces 1.2 and 1.7 litres of milk respectively on the average per day (Mamba [23]). On the average, a livestock-keeper sells 20% of his cattle, 37% of goats and 31% of sheep in a given year.

3. Results and Observational Discussions

3.1 Water – Use Sectors

Water uses were demarcated into three sectors. These were, agriculture (crops and livestock), environment (fish and maintenance of aquatic life) and domestic/industry (domestic water use and brick making) as presented in Fig. 2 and 3. Percentage water use per sector shows that the environment sector consumed the largest share of the reservoir yield (76.8%) followed by the agricultural sector (22.3%) and finally, domestic/ industry (0.9%). Meanwhile, incomes (fig. 3) from these do not commensurate water use. The situation in the Golinga area where water has already being committed is not an “environmental crisis” but a highly inequitable socioeconomic distribution of water resources requiring a re-distributive water allocation reforms, that can be likened to a recently launched South African government initiative (RSA, 2005).

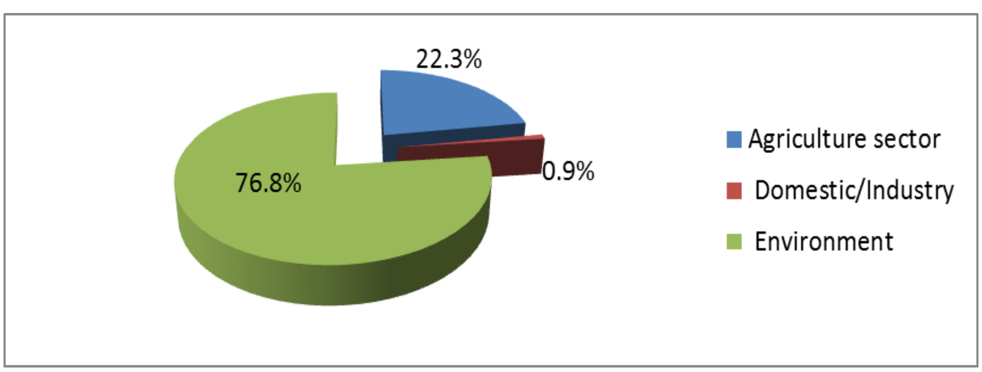

Figure 2: Major water uses –sectors by percentage

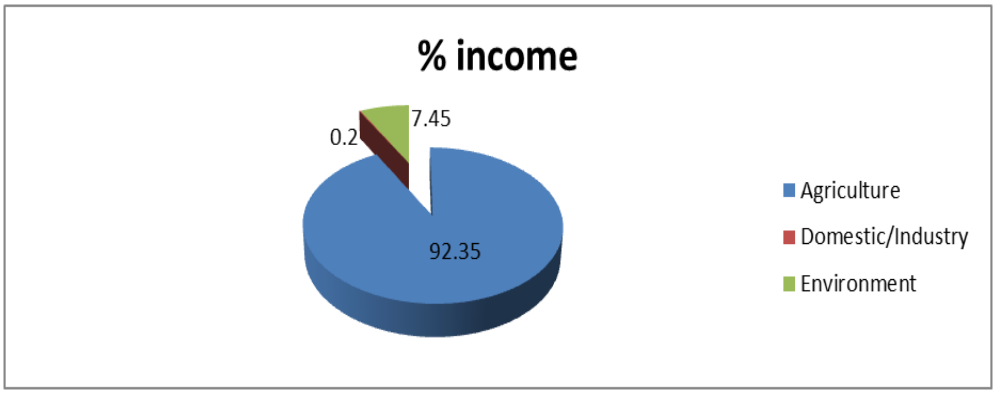

Figure 3: Incomes generated per water- use sectors

3.2 Maximum Dry Season Reservoir Yield

The results of maximum dry season reservoir yield (Mitchell [27]) show that reservoir storage ratios (SR) was equal to 3 (Table1). Storage ratio is a fraction of reservoir capacity to the quantity of runoff generated in the reservoir catchment. Small (SR)s meant that the catchments had underdeveloped water resources potential (GoZ, 2000). On average, only 16% of the MAR was stored in the reservoirs. A catchment that has storage capacity which is greater than twice and less than or equal to thrice (2<SR£ 3) MAR is classified as developed (GoZ, 2000). Development of more storage capacities in such a catchment results in incremental yield reduction (i.e. diminishing yield). The results also show that the reservoirs had low maximum dry season yield of between 4000 m^3 and 105 000 m^3 from a capacities of 12,000,000m^3 On average, dry season yield (219,143m^3) in the reservoir was just about 2% of the full supply reservoir capacity. The low dry season reservoir yield necessitate that users exercise prudent utilization of the scarce water resources since the rate at which the water resource is being replenished is very low .

Table 1: Estimating maximum dry season reservoir yield

$MAR(m^3)$	$RC_{MAX}(m^3)$	$RA_{max}(m^2)$	SR	EI	K_{factor}	$Y_{dry}(m^3)$	Remarks
1068	**12,300,000**	**28,020**	**3**	**0.002**	**0.99**	**219,143**	

NB; $RC_{max}(m^3)$ from (Gordon, 2006).

MAR - Mean Annual Rainfall derived from a 30yr average annual rainfall (AAR) data from Tamale meteorological station. $MAR = 0.0000467 AAR^{2.204}$

RC_{max} - Maximum Reservoir Capacity from (m^3)

$RA = K(RC)^u$ where;

RA_{max} - Maximum Reservoir Surface Area.(m^2)

K and u are parameters of variation between reservoir surface area (RA) and capacity

(RC). For most reservoirs, this relationship closely follows a power law. Mean value of "K" is 0.523 while the average value for the power "u" is 0.667 for "average reservoirs" of capacities ranging from 11 to 1300 mega cubic metres. (Mitchell [27]).

$$SR = \frac{RC_{max}}{MAR} = \text{Storage ratio.} \quad (3.2.1)$$

$$EI = 0.001(\frac{E_D \times RA_{\max}}{RC_{\max}}) \text{ = Evaporative Index} \quad (3.2.2)$$

E_D = Evaporation over the 5 months dry season period (mm).

$$K = e^{-0.9EI} \text{ = K-factor} \quad (3.2.3)$$

$$Y_{\max} = (\frac{(0.9K)}{(1-K)} - 0.15)EI \times RC_{\max} \text{ = Maximum dry season yield (m}^3\text{)} \quad (3.2.4)$$

3.3 Economic and Physical Water Productivity

Economic water productivity was determined in Ghana cedi (GHc) and converted to the United States dollar (US$). Livestock water use was observed to have the highest economic water productivity, with Cattle (57 US$/m^3) the highest, followed by Sheep and Goats (11 US$/m^3 each). It shows that much money can be made from a m³ of water by producing cattle than any other product (Table 2). A key livestock water productivity strategy requires increasing the productivity of each animal (Staal *et al.* [44]). Brick production was observed to have the highest physical water productivity followed by leafy vegetables and Fish as the lowest. However, Brick production (3500 kg/m^3) ranked fourth in economic water productivity at US$ 3.80/m^3 (Table 2). There were no physical productivities for the livestock due to the inability to weigh them. The economic water productivity of crops show that leafy vegetables (*Amaranthus spp*) (Ayoyo/Bra) US$1.86 had the highest productivity followed by pepper (*Capsicum spp*) (US$1.30), Onion (*Alliums spp*) (US$0.57) and Okra (*Hibiscus esculentus*) of about (US$2.9). Water losses in leafy vegetables production was higher than do in other crops. The estimation of water losses per quantity of farm produce and the causes of the losses may result in a reduction in the demand for water at the farm gate level (Molden *et al.* [29]), leading to significant improvement in water productivity. Judicious management of existing surface and groundwater resources is crucial for maintaining the food supply from irrigated agriculture (Rosegrant *et al.* [42]).

Table 2: Physical and economic WP calculation for various (existing) products

Water use Sector	Products	WP (Physical) kg/m^3	WP (Economic) GHc/m^3	WP (Economic) US$/m^3	Remarks
Domestic/ Industry	Brick	3500	5.50	3.80	
	Domestic		0.34	0.23	Half the price of piped system water was used
Environment	Fish	0.43	0.30	0.20	Evaporation losses
Livestock	Cattle	-	82.00	57.0	Manure/Milk/ Sales and Traction
	Sheep	-	16.00	11.0	Manure and Sales
	Goats	-	16.00	11.0	Manure and Sales
Crops	Leafy vegetable(Ayoyo/Bra)	6.50	2.70	1.86	59% Water losses
	Okra	0.48	0.42	0.29	33% Water losses
	Onion	2.26	0.83	0.57	35% Water losses
	Pepper	1.81	1.87	1.30	41% Water Losses

GHc 1.00 = US$ 1.45

Water productivity for fish was found to be the lowest (US$0.2/m^3) among the products considered (Table 2). This may be attributed to the high level of evaporation and low harvest. The average weight of fish caught per fisherman

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per day in the dry and wet seasons were 9.92 kg and 12.40 kg, respectively. Fish was sold at US$2.10 per bowl (Olonka) of 4.96 kg. The most common fish species caught was Tilapia (*Tilapia guinasana*). Tilapia comprises about 58% of the entire composition of fish species harvested from the dam. Others include Catfish (Black Bullhead) (*Ictaurus ameiurus melas*) and Pacific Herrings which were recorded as 42%.

Water productivity for domestic water use also recorded a value of US$0.23/m^3. Domestic water plays primary functions in the livelihood of a society. These primary functions include food preparation, sanitation and hygiene, drinking and laundry and are basic to the needs of the community and must have priority for use. Table 10 shows a five-month (dry season period) income per sector based on monetary water productivities. Average monetary water productivity values (US$/m^3) were used in calculating incomes for each of the sectors (agriculture, domestic/industry, and environment). From the Table, agriculture sector had the highest income per allocation (US$ 3,407,520.00) followed by environment (US$315,790.00) and domestic and industry (US$ 7,250.00). Results of the existing water allocation in the agriculture sector (Table 4) shows that crops used 94% of water allocated to the Agriculture sector but provided only 44% of the income as compared to what was used by the livestock sub-sector which consumed only 6% and provided 56% of the sector's income. Within the domestic and industry, domestic use, used up to about 94 % while bricks depleted only about 6 % (Table 5). The water productivity for domestic use was US$0.23 /m^3 while water productivity for bricks was US$ 3.80 /m^3 (Table 3)

Table 3: Scenario 1 - Existing sub-sectors of water use for dry season, 2009/2010

Sub-sector	**Consumption (m^3)**	**Sectoral water allocation % of total**	**Economic WP (US$/m^3)**	**Income generated**
Crop (Irrigation)	376,000	20.98	4.02	1, 511, 520
Livestock	24,000	1.34	79.0	1, 896, 000
Domestic	15,000	0.84	0.23	3, 450
Brick (Industry)	1,000	0.06	3.8	3, 800
Fish	23,000	1.28	0.2	4, 600
Maintenance of other Aquatic life	1,353,000	75.5	0.2	270, 600
Total Yield	**1,792,000**	**100.0**		

The results show that, utilisation of the water resources was not being optimised as observed from the 76.8 % available to the environment sector, fish production and other micro-organisms.

Table 4: Sectoral water use and allocation profile for agriculture

Sub-sector	**Consumption (m^3)**	**Sectoral water allocation % of total**	**Income generated USD**
Crop (Irrigation)	376,000	94	44.36%
Livestock	24,000	6	55.64%
Agriculture	**400, 000**	**100**	**3, 407, 520**

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Table 5: Sectoral water use and allocation profile for domestic and industry

Sub-sector	Consumption (m^3)	Sectoral water allocation % of total	Income generated	% income generated
Domestic	15, 000	93.75	3, 450	47.59
Brick	1, 000	6.25	3, 800	52.41
Domestic/ Industry	**16,000**	**100**	**7, 250**	**100**

Table 6: Sectoral water use and allocation profile for environment

Sub-sector	Consumption (m^3)	Sectoral water allocation % of total	Income generated	% income generated
Fish	23,000	1.67	4, 600	1.67
Maintenance of other aquatic life	1, 353, 000	98.33	270, 600	98.33
Environment	**1, 376, 000**	**100**	**275, 200**	**100**

3.4 Water Allocation Strategy and Scenario Development

In a community where a resource is for a communal use there must be an understanding among the members of the community regarding water sharing and usage. Water allocation scenario is carried out as a way of developing and understanding water use options at all in times in order to maximise the benefits derived from services or produce per unit of water consumed. Water productivity concept helps us to do this. Once water productivities are calculated, water allocation to different uses can be done. Water productivity values for each water use/sector is determined and used as a basis for resource sharing or allocation.

Four water allocation scenarios were considered based on the prioritised societal value of cash (income) to arrive at an agreeable water allocation strategy. Present water availability, allocation, use and income derived could be clearly understood and manipulated depending on the needs of the community and anticipated future demands. The study found that total water allocation for agriculture, domestic and industry, could still be increased from present allocations without jeopardising the environment sector. Therefore, in scenario 2, part of the 76.8 % of the environment sector could be appropriated on more productive sectors (i.e. agriculture and domestic/industry), leaving sufficient quantities (i.e. 11 % of available yield) for the sustenance of the environment sector (Nguyen-Khoa *et al.*[32]; Renwick [40]). Also within the agriculture sector, more water can be allocated to the more productive livestock sub-sector, from the crop sub-sector. This may be done through reduction of area under cultivation or more appropriately, prudent crop water management. However, production of livestock must be controlled to avoid impacting negatively on other natural resource base. For domestic water use, water allocation may be decreased by urging communities that have a more portable water source, to meet their per capita water demand, especially for drinking from alternative and safer water sources such as boreholes available in the area. Thus, maintaining scenario one (1) would result in water resources being inappropriately and inefficiently allocated to less productive sectors.

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Table 7: Re-allocating waters within sectors (Scenario 2)

Sub- Sector	Re-allocation by % within sectors	Scenario 2 Allocations (m^3)
Crop Irrigation	90	360,000
Livestock	10	40,000
Brick (Industry)	20	3,200
Domestic	80	12,800
Fish	30	412,800
Others	70	963,200
Total Yield		**1,792,000**

3.5 Scenario 2: Reallocating Waters within Existing Water use Sectors

Re-allocating water across "sub-sectors" with higher water productivity sectors, gave higher water productivities as presented in Tables 4, 5 and 6. Table 9 shows that income levels can improve if water was allocated only to those sub-sectors that had higher water productivities within the sectors considered. It was important to re-allocate the substantial amount of water lost to deep percolation (Table 2), to livestock production, which had a higher productivity (Table 4). Also in the allocation strategy, 11% of full supply reservoir capacity could be sufficient for the sustenance of aquatic life, including fish (Nguyen-Khoa *et al.*[32]; Renwick [40]). The resultant improved incomes for agriculture, environment and domestic and Industrial sectors are *US$ 4,607,200.00*, *US$ 82,560.00* and *US$ 15,104.00* respectively. Thus, showing an increase of about 26% realised over the income for the scenario 1 (Tables 4, 5 and 6).

3.6 Scenario 3: Re-allocating Water Across "Sectors" with Higher Water Productivities

Scenario three (3) is aimed at re-allocating water across sectors (products or uses) which had higher water productivities as presented in Table 8. As a result of the reallocation of 30% and 25% of total water-used to agriculture and domestic and industry sectors respectively, there was a higher improvement in their incomes.

Table 8: Reallocate water across sectors (Scenario 3)

Sector	Scenario 1, (m^3)	Scenario 3, (m^3)	AV.WP(US$/$m^3$)
Agriculture	400,000	806,400	12
Domestic/ Industry	16,000	537,600	2
Environment/Fishery	1,376,000	448,000	0.2
Total Yield	**1,792,000**	**1,792,000**	

The environment/fishery sector allocation was substantially reduced to allow for its water re-allocation to other more productive sectors such as agriculture and domestic/industry. This affected the income from the environment sector but not the over all productivity. This strategy resulted in an increase (191%) in productivity (Table 10).

3.7 Scenario 4: Distributing the Sectorally re-distributed waters of Scenario 2

This is to re-allocate waters of the second scenario across sub-sectors of scenario1. It was aimed at distributing, re-distributed waters of scenario 3 unto sub-sectors of high productivity in scenario 1. This is similar step to that of scenario 2. Table 10, shows a dramatic increase of income to the tune of 196% from scenario 1, based on intra sub-sector redistribution. The incomes from the sectoral distribution of water resources per scenario are, US$ 9,288,115.00, US$1,659,034.00 and US$ 103,040.00 for agriculture, domestic/industry and environment, respectively.

Table 9: Distribution of re-distributed water with the sectors

Sector	% Scenario 2	Scenario 4 (m^3)	WP (US$/$m^3$)
Crop	90	725,760	4.02
Livestock	10	80,640	79.00
Domestic	20	107,520	3.80
Brick(Industry)	80	430,080	2.30
Fish	30	134,400	0.23
Others	70	313,600	0.23
Total Yield		**1,792,000**	

Table 10: Incomes generated for Scenario 1 - 4

Sector	Scenario 1, (US$)	Scenario 2, (US$)	Scenario 3, (US$)	Scenario 4 (US$)
Agriculture	3,407,520	4,607,200	9,676,800	9,288,115
Domestic/Industry	7,250	15,104	1,075,200	1,659,034
Fish/ Environment.	315,790	82,560	89,600	103,040
Total Income	**3,730,560**	**4,704,864**	**10,841,600**	**11,050,189**
Overall increase (%)	**0.00**	**26**	**191**	**196**

4. Conclusive Observations

In this paper, cost-effective perspective and scenario development on economic optimization for multiple-use dry-season water resource has been confined comprehensively. Total water productivity and statistical estimation of water productivities have been mainly focused in order to draw following some conclusive observations:

- Present study finds many more important sources of water supplies such as small and medium scale reservoirs for supporting socioeconomic activities in the Northern Region of Ghana.
- Irrigation, livestock, and fisheries are the three most important reservoir water uses within the Golinga reservoir water resources. However, brick making has been identified as an additional important water use sub-sector from which maximum benefit can be derived.
- Although the role of reservoir water in supporting multiple uses is commonly acknowledged, planning of water use in Golinga is generally based on water requirements for irrigation supply only yet a high ratio of the water released relative to water requirements points to the mismatch between irrigation water supplies and potential crop water demand, contributing to high water losses and thus low WP. As a result, crop water WUE was very much lower in leafy vegetables (41%) compared to onion and okra which were 65% and 67%, respectively.
- The four scenarios (strategies) considered in the selection of the best water allocation strategy illustrates that water productivity can be used as a tool for formulating water allocation among various uses. It indicates also that the current water allocation was not based on the value of uses.
- The strategy that had ultimate significant contribution to the prioritised social objective of cash (income) was the distribution of allocated water across sectors with high water productivities. Total income can increase to 190% over the current situation depending on strategy used.
- The study argues that any produce with low water productivity values should be considered under the virtual water concept or should be produced during the rainy season when water resources are relatively

abundant. Hence, scarce water resources should be allocated to sub-sectors (products) with higher water productivities without impairing environmental capacity and domestic water supply.

- The results in the present paper also provide useful information for seasonal planning of reservoir water resources under multiple water uses and show how important brick water allocation is, given the competing uses.

- If required, a decision maker can also draw some other valuable and relevant information from respective tables 1-10.

- A comparative study for multiple-use-dry water resources can be considered for dams in India and other countries by future researchers.

Acknowledgement

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