# *Estimation of Livestock, Domestic Use and Crop Water Productivities of SG-2000 Water Harvesting Pilot Projects in Ethiopia*

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**December, 2006**

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**Abbreviations**

ILRI- International Livestock Research Institute

IWMI- International Water Management Institute

SG-2000- Sasakawa Global -2000

OIDA- Oromia Irrigation Development Authority

MoFED- Ministry of Finance and Economic Development

CSA- Central Statistical Authority

EDRI- Ethiopian Development Research Institute

WHO- World Health Organization

LWP- Livestock water productivity

DWP- Domestic water productivity

CWP- Crop water productivity

**Acknowledgments**

This paper is the result of my internship program to accomplish an MSc in Environmental Science, Wageningen University, The Netherlands. To this end, International Livestock Research Institute (ILRI) and International Water Management Institute (IWMI) at Addis Ababa, Ethiopia deserve many thanks for providing me with the opportunity to do this paper. I appreciate Dr. Shirley Tarawali (ILRI) for her quick and on time responses for my internship requests before I came to Ethiopia for this purpose. My special thanks to my supervisors in Ethiopia Dr. Don Peden (ILRI) and Dr. ir. Eline Boelee (IWMI) for their valuable comments, discussion and supplying me with important reading materials during the research work. I am also indebted to Dr. Girma Taddesse (ILRI) for his continuous support to facilitate things, supplying me with different reading materials, introducing me with his other staff members and making possible for me to access some of the facilities in ILRI.

This research would have not been completed with out people in SG-2000 who helped me to obtain the necessary data for this paper. Special thanks to Dr. Abera Debelu for his permission to get the data and Dr. Dejene Aredo & Ato Wondewesen Tsegaye for their cooperation to make the data available for me.

I thank also Ato Wagnew Ayalneh, Dr. Amare Haileselasse, Ato Solomon G/egezabehre and Ato Micheal Asrat for their valuable discussions we made in the research process.

**Abstract**

*Water scarcity in these days is a real threat to food production for millions of people in arid and semiarid areas of developing countries. As water becomes one of the most scarce resources in these poor developing countries, the only option available to get out of poverty is to improve the productivity of water in every sector of production. Currently, in some of water stressed areas of Ethiopia, water harvesting technologies are being introduced in the view to secure food through irrigation practices. The major objective of this paper is, therefore, to estimate livestock, domestic use and crop water productivities of SG-2000 water harvesting pilot projects in Ethiopia. The research work is entirely based upon secondary data obtained from various organizations and publications. The water productivity magnitudes for livestock, domestic and crop productions are found to be Birr[*] 40.71, 213.42 and 8.04 per m3 of water respectively. To show the importance of the opportunity cost of water, these productivity values are recalculated taking the market price of water in rural areas as the denominator. As the result, livestock, domestic use and crop water productivity magnitudes, respectively, are birr 1.63, 8.54 and 0.32 per birr of water. The research finding shows that water used for domestic use and livestock generates the greatest benefit for rural households.*

# I- Introduction
### *1.1- Background*

A debate can under go whether livestock production or crop cultivation may be preferred as an important pathway for a farmer to get out of poverty in water scarce areas of developing countries like Ethiopia. For instance Peden et al (2005(a)) argues that because animal products have high value compared with most staple plant based foods, livestock production will likely be increasingly valued as an effective strategy to alleviate poverty in situations where market opportunities exist. According to these authors, water productivity of animal products derived from consumption of crop residues is competitive with crop production thus in terms of water productivity livestock can make an important contribution to poverty alleviation. However, SIWI states that water requirements to produce one kg of grain-fed beef and poultry require at least 15$m^3$and about 5$m^3$ respectively, but grains, pulses, and root crops require less than two $m^3$/kg produced. Such figures have led many policy makers and investors to conclude that animal production should be discouraged because it uses too much water in a water scarce world (Peden et al 2005(b)). These conflicting views may arise due to the ignorance of the important roles livestock play in contributing high quality food products to human diets and in providing animal power for crop production that enhances food security in most agricultural water development. In other words, there seems usually undervaluation of benefits from livestock in the planning of many agricultural development projects in developing countries. Thus, promoting the multiple use of water (MUS) in these water scarce areas certainly increase the water productivity (WP) provided the existing water resource is not optimally used yet. That means, WP can be improved if the available water is under utilized and the extra investment costs to generate extra benefits from water in a certain irrigation and/or harvested water schemes are low compared to extra benefits.

Even if, theoretically, one of the practices (livestock or crop) may generate higher WP, it would be very difficult to recommend for a typical farmer in Ethiopia to follow producing only one of the two depending on the magnitude of WP. Because in drought prone areas livestock serve as copping mechanisms (store of assets),

[*] Birr is Ethiopian currency. Currently 1U.S.Dollar = 8.5 birr.

provide animal power, manure, increased enhanced year-round nutrition and have cultural values. These animal services may not have any substitution for poor farmers and in localities where there are no market access. Thus, the main focus of the analysis of WP in the mixed crop-livestock farming practice would be how farmers maximize the total WP in agriculture and how they optimally combine the two practices so that they can use water to get out of poverty. Evidences suggest that integrating investments in agricultural water with livestock will benefit both sectors and lead to overall improvements in livelihoods and decreased poverty. Ignoring this option often leads to lost opportunities for benefits, contamination of agricultural water resources, degradation of irrigation infrastructure and conflict especially between pastoralists and farmers (Peden et al 2005(b)).

International livestock research institute (ILRI) with its partners such as International water management institute (IWMI), Ethiopian agricultural research organization (EARO), Sasakawa global 2000 (SG-2000) and with others has conducted different studies on the interactions of water and livestock from the point of view of alleviating poverty in Ethiopia. Among the many studies so far have done, the author have found two studies ( Puskur et al., 2005; Taddesse et al., 2006) which have tried to show the economic benefit-cost analysis from the newly developed water schemes. The study by Puskur et al., (2005) collected primary data using survey questionnaire in a sample of 25 farming households drawn from SG-2000 sites in Oromiya region. This study has found an improvement of direct benefits from livestock products in terms of quantity and value of production among the participant households after they developed water schemes for crop and livestock production purposes. Taddesse et al., (2006) adopted a relatively detailed benefit-cost analysis in Woredas covered by SG-2000 water harvesting and utilization pilot projects. According to this study, the net income of a household from vegetable, green maize, and livestock is 9980 birr/year/project, which, according to the researchers, encourages the farmers to have dairy cows at household level given access to veterinary services. Taddesse et al., also calculated net income of 7,740 birr/cow/household and they concluded that the project is viable. According to this source, the water productivity varies from 3.6 kg to 9.1 kg per m3 for onion and combination of onion and tomato respectively and the productivity of green maize is about 29 cobs per m3 of water. While Taddesse et al. didn't show the water productivity of livestock in terms of money and physical quantities, they tried to show the over all benefit cost ratio of livestock production in the project areas. Livestock benefit-cost ratio was found to be 4.3, that means for every one birr spent, the beneficiary has got birr 4.3 from livestock production.

In general, these two studies have shown that the water schemes have contributed to improve the income of the households in the project areas based on the monetary values of direct benefits and costs. The studies, however, didn't show the livestock water productivity in the one hand and the indirect costs and benefits from the water schemes. Thus, this study will try to assess agricultural water productivity from the point of view of multiple use of water resources in Oromia and SNNP regions of Ethiopia.

### *1.2- Statement of the problem*

Countries, according to he World Bank (Deng 2000) are grouped by aridity into three categories:

- *Category 1* consists of countries in which 75 percent or more of the total land area is drylands (i.e., arid, semi-arid, and dry sub-humid);
- *Category 2* consists of countries in which drylands make up less than 75 percent but more than 50 percent of the total land area; and
- *Category 3* consists of countries in which drylands make up 50 percent or less of the total land area.

According to the same source, other things being equal, category 1 countries are assumed to be more likely to have human-induced land degradation than a country in category 2 or 3. Thirty-seven (37) countries are in category 1, of which 23 and 12 are from Africa and Asia, respectively. This classification shows that about two-thirds of category 1 countries are in Africa including Ethiopia (or 56 percent of African countries are in category 1). Water scarcity is therefore a real threat to food production for millions of people in these arid and semiarid areas.

Water scarcity, According to Pereira et al., (2002) is commonly defined as a situation where water availability in a country or in a region is below 1000 m3 per person per year. However, many regions in the World experience much more severe scarcity, living with less than 500 m3 per person per year, which could be considered severe water scarcity. The threshold of 2000 m3 per person per year is considered to indicate that a region is water stressed since under these conditions populations face very large problems when a drought occurs or when man-made shortages are created (ibid).

The countries of Africa have been experiencing an ever-growing pressure on their available water resources, with increasing demand and costs for agricultural, domestic and industrial consumption. Of the many countries around the world currently classified as water-stressed, more are in Africa than in any other continent (Engelman and Le Roy 1993 in Meselech 2005). In the African context, natural occurrences of hazards such as drought, desertification, and climate change and the influences of human activities like agriculture, population growth, industrial development, and land use changes are considered to constitute the major causes of the continuing deterioration of freshwater resources. These pressures have caused both environmental deterioration (including pollution of freshwater systems) and overexploitation of important water catchments, resulting in lowered groundwater levels (ibid).

Further more, as the world population continues to grow, the arable land area per capita will further decrease. The Food and Agriculture Organization (FAO 1988 in Zhang 1999) estimated that almost two-thirds of the increase in crop production needed in the next decades must come from higher yields per unit of land. Hence, rainfall and irrigation water must be used more efficiently and water productivity increased (ibid).

Literatures also show that with the human population in Africa expected to grow by more than 50% over the next 20 years, investments to increase food production must correspondingly follow. In these days, food production uses more than 70% of managed water in developing countries. Achieving a 50% increase in food production with the same amount of water is not possible without increasing water use efficiency (Anonymous in Peden et al 2005(b).

However, Sub-Saharan Africa farmers run the risk of total crop failure due to drought once every five years and severely reduced yields once every two years (Molden and

Fraiture 2004). For instance, Ethiopia has nine major rivers, totaling 6400 km with an annual discharge of 63 billion cubic meters of which the Blue Nile accounts for 80%. However, water is a very scarce commodity for many the smallholder farmers and their livestock, and the situation is aggravated by seasonal variations in availability of water (McCornic et al., 2003).

In areas where water is one of the most scarce resources, integrated water development investments taking into account the multiple use of water services (MUS) are believed to increase the productivity of water in agriculture and helps to improve the living standard of poor households. Hence, apart from crop production using the available water through irrigation in a certain water scheme, it is also recommended to include livestock production in the venture and at the same time to use this water for household productions.

Livestock products comprise an important component of agricultural production but have largely been ignored in water management for food security (Lardy 1999; Peden et al. 2003 & 2005 in Girma et al. 2006). For instance, most of the scientific literatures on water use by livestock in Africa focuses on drinking water (Seleshi et al 2003; Peden et al 2003 in Peden 2005(b) but this amounts to about one percent of the waters animals require. In contrast, water used to produce feed can account for up to 99% of the water used by animals. These observations show that there is a crucial knowledge gap exists in understanding the role of livestock in overall water use and the efficiency of water use in livestock production. Animal production needs to be part of the solution and not the problem (ibid).

Health problems are also commonly associated with water scarcity, not only because the deterioration of the groundwater and surface waters favours water borne diseases, but because poverty makes it difficult to develop proper water distribution and sewerage systems. Though adequate water supply, according to Howard et al., (2003) is defined as 20 litres per capita per day made available within a range of one to two kms from the dwelling, in some areas of Ethiopia average per capita water consumption varies between 10 and 20 litres per day (Getachew 2005). However, in most rural areas of Ethiopia, depending upon seasonality and location of source and availability of water, daily consumption is as low as 3–4 litres per capita per day. Women and children particularly girls have to fetch water, often walking for 3–8 kms from their dwellings. As a result of this water scarcity, about 80% of the diseases in Ethiopia are communicable in nature, which can be easily prevented or controlled by applying simple sanitary measures such as provision of safe and adequate food and water supplies, safe and adequate waste disposal system, vector control and the promotion of personal, family, neighborhood and community hygiene and sanitation (Getachew 2005).

### *1.3- Objective of the study*

Sustainabily meeting the food and livelihood needs of a growing population in a drought prone areas will require some very difficult choices about how water can be used optimally among different competing activities in agriculture. So, the major objectives of this study are to quantify and analyze agricultural water productivity in Oromia and Southern regions of Ethiopia . The specific objectives of the study are:

- to estimate livestock, domestic use and crop water productivity magnitudes;
- to compare and contrast water productivity values of the three sectors: crop, livestock and domestic use;

- to find the way how we can maximize water productivity by identifying the existing constraints in agricultural water use.

### *1.4- Research questions*

In this study the following research questions will be answered

- How much are the magnitudes of livestock, domestic use and crop water productivities in the study area?
- What are the major influencing factors of water productivity?

### 1.5- The study area

The study area covers most parts of East Shewa zone of Oromia and some parts in Southern region of Ethiopia. This area is selected for this study because much of the localities are water stressed areas and therefore much of actively operating harvested water schemes in the country are found here. Similarly, the major source of data for this study is Sasakawa Global 2000 (SG-2000) which is an established NGO in Africa sponsors small-scale farm level water harvesting projects with the objective of poverty alleviation and enhancing food security. More than 90% of water harvesting pilot projects of SG-2000 are found in this study area.

### *1.6- Methodology of the study*

This study is entirely based upon secondary statistical data obtained from various sources and organizations, such as Sasakawa Global 2000, ILRI, IWMI, Central Statistical Authority (CSA), Ministry of Agriculture, Oromia Irrigation Development Authority, Oromia Health Bureau, Ministry of Finance and Economic Development and others.

The productivity analysis is done using descriptive statistics such as mean, percentage, frequency, standard deviation, etc by computer soft wares Excel and SPSS.

### 1.7- Limitations of the study

The major limitation of this study emanates from the data that are used to quantify and analyze WP values in the study areas. The data used are secondary data obtained from different organizations and publications. Since the objectives of collecting these data by respective organizations are different from the objectives of this study, there has been some difficulties to make these data fit into this paper. In some cases even, there were no any quantitative data available any where. As a result, expert judgments are used to estimate the values of some variables that should be included in the analysis. All these problems, though they don't bring to a halt the research work, the quality of the research findings would be even better if primary data were collected by the researcher.

### 1.8- Scope and organization of the paper

This study highly deals with the quantification of magnitudes of livestock, domestic use and crop water productivities of harvested water in SG-2000 sites. The paper is made up of six sections. The first section presents some introductory notes, the second discusses the conceptual framework of WP, the third emphasizes on factors affecting agricultural WP, the fourth devoted to highlighting the existing situations of water harvesting practices & water use in Ethiopia, the fifth section concentrates on the calculations of WP magnitudes in the study areas, and finally concluding remarks & some recommendations are forwarded.

## II- Conceptual framework

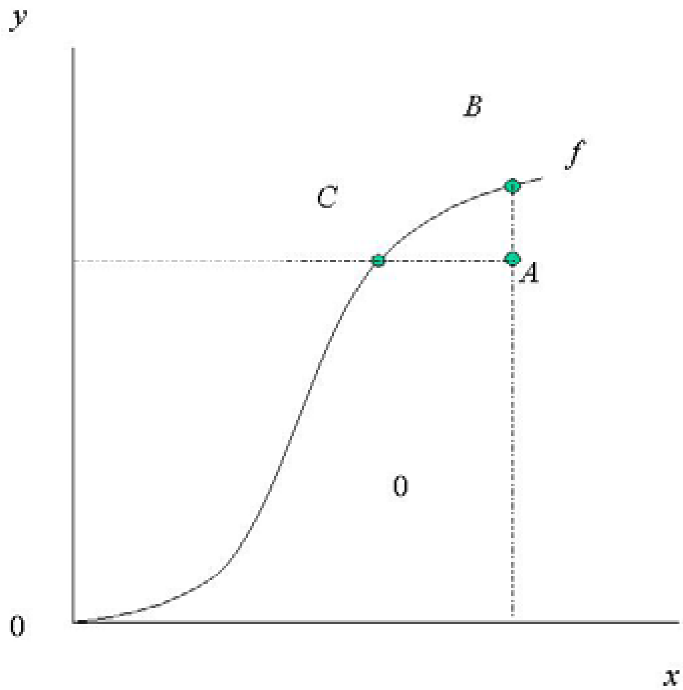
The concepts of ‘water use efficiency’ and/or ‘water productivity’ are defined and used differently by different professionals. The first use of the term ‘water use efficiency’ to mean the ratio of crop production to evapotranspiration was by Viets in 1966 (Kijne et.al. 2000). This agronomic view has since become widely used to describe the yield per unit of water. The engineering definition differs from the agronomic one in which water use efficiency means the ratio of the amount of water stored in the root zone to that delivered for irrigation. Irrigation engineers also use the term ‘irrigation efficiency’ to designate the water used by the crop divided by the water delivered (ibid). According to the same literature, recently several alternative definitions have been proposed by different people. For instance Willardson et al. (1994) introduced the concept of consumed fractions and others such as Perry (1996), Clemmens and Burt (1997), and Molden (1997) have referred to beneficial and non-beneficial depleted or consumed fractions of water. Economists also use factor productivity to refer the value of output divided by the value of all inputs. Any way, most analyst in the water sector agrees in the preposition that water use efficiency “includes any measures that reduce the amount of water used per unit of any given activity, consistent with the maintenance or enhancement of water quality” (Tate 1994 in Pereira 2002). Depending on how the terms in the numerator and denominator are expressed, water productivity can be expressed in general physical or economic terms as follows (Seckler et al. 1998 in Kijne et al. 2000):

a) Pure physical productivity is defined as the quantity of the product divided by the amount of water depleted or diverted.
b) Combined physical and economic productivity is defined in terms of either the gross or net present value of the crop divided by the amount of water diverted or depleted.
c) Economic productivity is the gross or net present value of the product divided by the value of the water diverted or depleted, which can be defined in terms of its value or opportunity cost in the highest alternative use.

To elaborate further the concepts of efficiency and productivity the science of economics makes a distinctions between technical efficiency, allocative efficiency and the combination of these two- economic efficiency.

Technical efficiency is a measure of how well the individual transforms inputs into a set of outputs based on a given set of technology and economic factors (Aigner et al., 1977; Kumbhakar et al., 2000 in Shih et al., 2004). Two individuals using the same set of inputs and technology may produce considerably different levels of output. While part of the difference may just be random variations found in all aspects of life, other parts may be attributed to individual fundamental attributes and to opportunities that could be influenced through public policies (ibid). For example, does education or the age of the operator make a difference? One attribute may be influenced by public policies while another is not. Yet, in both settings, the impact of these attributes on the level of output can sometimes be measured. Without going into great detail, the concept is easily illustrated using the example (figure 1) below in which *y* represents quantity of output such as crop in k.g and quantity of input labor x in man day is the only variable input while all other inputs (e.g land, machinery, etc.) remain constant in the short run.

*Figure 1- production frontier-showing the law of diminishing returns to the variable input labor*



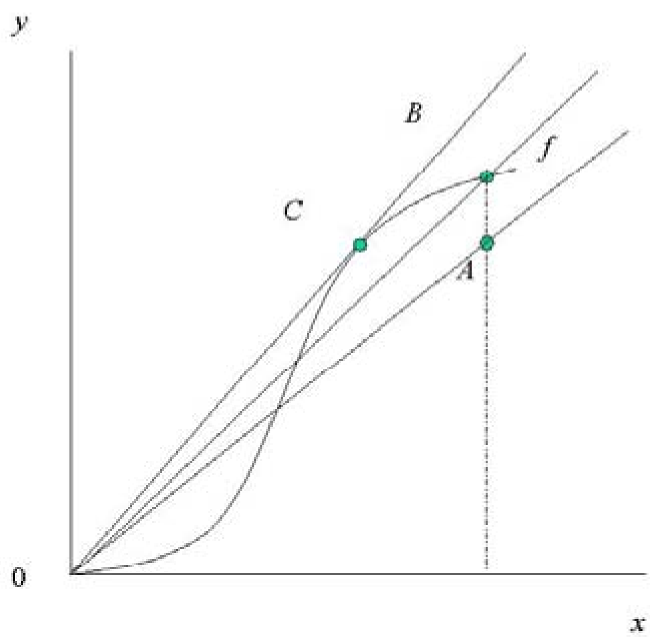

*Source: Shih et al., (2004), Economies of scale and technical efficiency in community water systems, Discussion Paper 04–15, Resources for the Future 1616 P Street, NW Washington, D.C. 20036*

Figure 1 shows a simple production process in which a single input say, labor (x) is used in various quantities to produce a single output, say crop (y). The curve 0f represents the production frontier or the production function, which is the maximum output attainable from each input level. It reflects the current state of technology of the farmer. All points between the production frontier and the x-axis form the feasible production set. Technically efficient farmer operates on the frontier, and inefficient ones operates below it with the ratio of the actual to potential production defining the level of efficiency of the individual farmer. For example, Point A represents an inefficient point whereas points B and C represent efficient points. A farmer operating at point A is inefficient because technically it could increase output to the level associated with the point B without requiring more input or it could reduce input to the level associated with the point C without reducing any output production. With more than one input the concept is the same, but the figure has three or more dimensions (Shih et al., 2004).

Individuals using the same set of inputs, but with values below the production frontier, are considered less technically efficient. This leads to two questions that must be answered. First, to what extent do the production units lie below the frontier? Second, what factors influence production units lying below the frontier? One way to reveal potential efficiency problems is to measure farm output lying below the estimated frontier.

In Figure 2 below, we use a ray through the origin to measure productivity at a particular data point. The slope of this ray is y/x (output/input) and hence provides a measure of productivity of input x (ibid). If the farmer operating at point A were to move to the technically efficient point B, the slope of the ray would be greater, implying higher productivity at point B. However, by moving to the point C, the ray from the origin is at a tangent to the production frontier and defines the point of maximum scale economies. In other words, point C represents the maximum for average product (AP) or alternatively the minimum for average cost (AC) of production since cost functions are the inverse functions of production functions. Here it should be noted that as the ray shifts upward the slope of the ray increases implying the productivity of the input increases continuously but the further shift of the ray beyond point C is unattainable. So, the maximum possible productivity would be point C. From this figure we conclude that a farmer may be technically efficient (point B) but he may still be able to improve his productivity by exploiting scale economies (point C).

*Figure 2- Productivity, efficiency, and scale economies*




*Source: Shih et al., (2004), Economies of scale and technical efficiency in community water systems, Discussion Paper 04–15, Resources for the Future 1616 P Street, NW Washington, D.C. 20036*

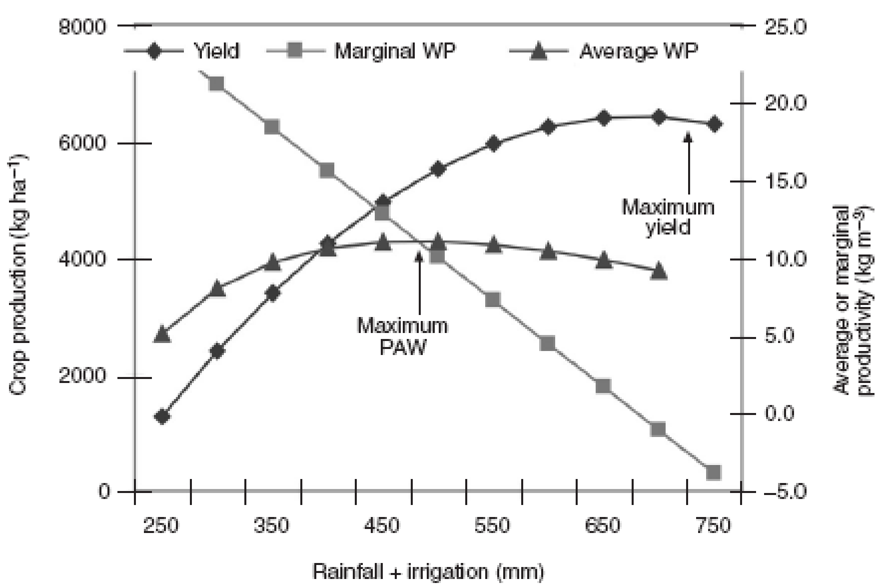
Economies of scale result from increases in the size of the scale of the operation of the farm activity. As a size of a certain farm practice increases to a certain level its inputs especially the fixed inputs efficiency increases and hence the average cost of production falls down but after a certain point of production as a farm continues to increases its operation there will be diseconomies of scale implies the fixed inputs are excessively used and then the average cost of production will rise up.

The relevance of scale economies in this study is very important since one of the objectives of ILRI/IWMI is to promote multiple use of water to the community so that much output can be produced with less increment of the cost of providing those benefits of water. For instance, whenever animals trek long distances to find drinking water, herders reduce watering frequency to every two or three days, resulting water stress that reduces animal production. If this problem be solved by using the existing water for animal drinking purpose through some extra investment, WP will rise up since providing sufficient water to animals improves animal growth, efficiency of feed conversion and milk production (Stahel et al 2001; Multi 2000 in Peden et al 2005 (b)). In addition, herd keepers can save some time and their energy that otherwise would have been wasted by traveling longer distance to find animal drinking water. The economies of scale of water use will further be higher if much of the beneficial of the project would be women as the marginal utility derived from one extra unit of benefit for the disadvantaged group of a community is greater than the marginal utility of the favored group.

When one considers productivity comparison through time, an important source to increase productivity is technological improvement in production. As technology of production improves the production frontier will shift up ward and hence we can produce more output using less input or the previous level of output can be produced with less input. In general increased productivity may be due to three factors: increased technical efficiency, exploitation of scale economies and technological change.

The concept of the law of diminishing returns to the variable input (figure 1 above) is also relevant to elaborate the concept of water productivity as depicted in figure 3 below. Assume, according to Zhang *et al.*, (1999), a production function in which crop yield (Y) is a function of the amount of water received by the crop in terms of rainfall (P) and irrigation (I) can be defined as follows: $Y = f(P, I)$. The average yield $\overline{Y}$, which is output divided by input, can be written as $\overline{Y} = Y/(P + I)$.

*Figure 3-Relation of crop production, productivity of applied water (PAW) and marginal productivity to the crop water supply. The arrows indicate that the maximum PAW value occurs at a lower value of applied water than maximum yield does.*




*Source: Zhang H. (1999), Improving Water Productivity through Deficit Irrigation: Examples from Syria, the North China Plain and Oregon, USA, CSIRO Plant Industry, Wembley, Australia.*

The marginal yield $(\hat{Y})$ is defined as the change in production associated with the addition of one unit input. It can be written as

$$\hat{Y} = \partial Y / \partial (P + I)$$

The maximum yield is achieved when the marginal yield is equal to zero. Maximum water-use efficiency requires that the derivative of the average yield is equal to zero, $[\partial Y / \partial (P+I) - (Y / P + I)] = 0$, the average yield reaches its maximum when it is equal to the marginal product. In other words, as long as some quantity of water is applied, water-use efficiency is maximal where it is equal to the marginal production. As far as yield doesn't reach at its maximum, the producer must increase the use of water to reach at the highest level of yield. From the origin up to the maximum level of yield (in the feasible production range) each extra use of water brings about positive marginal yield and when yield is at its maximum the marginal yield becomes zero. The rational producer, therefore, doesn't use any extra water (from rainfall and irrigation) beyond the point where yield reaches at its maximum. Any extra water use beyond the maximum yield will result in lower output and hence the cost of production rises up. In other words, beyond the maximum yield the marginal yield from each additional water becomes negative, i.e., wastage of water or inefficiency in the use of water.

Similar results to the relationships shown in figure 3 above were found from the case studies of crop–water production functions for wheat produced from supplemental irrigation experiments conducted in Syria (Zhang and Oweis, 1999), the North China Plain (Zhang *et al.*, 1999) and Oregon state, USA (English and Nakamura, 1989) using the quadratic production function $Y = b_0 + b_1(P + I) + b_2 (P + I)^2$ which was used to describe the response of wheat yield to total applied water. In this equation Y represents wheat yield (ton $ha^{-1}$), I is the irrigation water (mm) and P is precipitation (mm) (Zhang 1999).

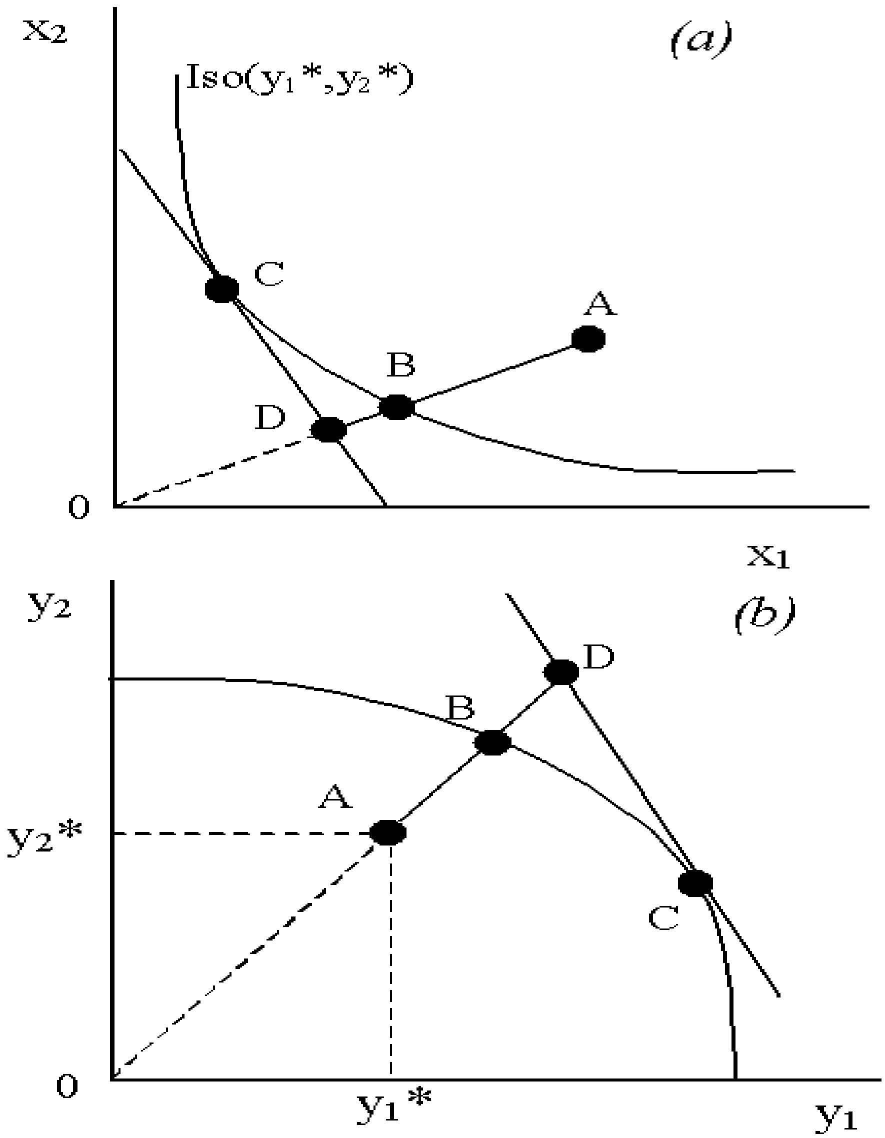
It should be noted that an increase in water productivity may or may not result in higher economic or social benefits. Economists distinguish between net private returns (i.e., the market value of all outputs minus the cost of all inputs, considering the opportunity cost of all inputs not purchased on the market such as family labor and land) and net social returns (i.e., the value to society of all outputs minus those of all inputs) (Barker et al. 2002 in Kijne et al. 2000). Thus, what becomes important to improve the welfare of farmers is due consideration should be given to assess the working of markets of inputs and outputs where prices are determined.

Proceeding to the analysis of efficiency, technical efficiency is just one component of overall economic efficiency. However, in order to be economically efficient, a firm must first be technically efficient. Profit maximization requires a firm to produce the maximum output given the level of inputs employed (i.e. be technically efficient), use the right mix of inputs in light of the relative price of each input (i.e. be input allocative efficient) and produce the right mix of outputs given the set of prices (i.e. be output allocative efficient) (Kumbhaker and Lovell 2000 in Herrero et al., 2002). These concepts can be illustrated graphically using a simple example of a two input ($x_1$, $x_2$)-two output ($y_1$, $y_2$) production process (Figure 3). Efficiency can be considered in terms of the optimal combination of inputs to achieve a given level of output (an input-orientation), or the optimal output that could be produced given a set of inputs (an output-orientation).

In Figure 3(a), the firm is producing a given level of output ($y_1^*$, $y_2^*$) using an input combination defined by point A. The same level of output could have been produced by radially contracting the use of both inputs back to point B, which lies on the isoquant associated with the minimum level of inputs required to produce ($y_1^*$, $y_2^*$) (i.e. Iso($y_1^*$, $y_2^*$)). The input-oriented level of technical efficiency ($TE_I(y, x)$) is defined by 0B/0A. However, the least-cost combination of inputs that produces ($y_1^*$, $y_2^*$) is given by point C (i.e. the point where the marginal rate of technical substitution is equal to the input price ratio $w_2/w_1$). To achieve the same level of cost (i.e. expenditure on inputs), the inputs would need to be further contracted to point D. The cost efficiency (CE(y,x,w)) is therefore defined by 0D/0A. The input allocative efficiency ($AE_I$(y,w,w)) is subsequently given by CE(y,x,w)/$TE_I$(y,x), or 0D/0B in Figure 3(a) (ibid).

The production possibility frontier for a given set of inputs is illustrated in Figure 3(b) (i.e. an output-orientation). If the inputs employed by the firm were used efficiently, the output of the firm, producing at point A, can be expanded radially to point B. Hence, the output oriented measure of technical efficiency ($TE_O$(y,x)), can be given by 0A/0B. This is only equivalent to the input-oriented measure of technical efficiency under conditions of constant returns to scale. While point B is technically efficient, in the sense that it lies on the production possibility frontier, a higher revenue could be achieved by producing at point C (the point where the marginal rate of transformation is equal to the price ratio $p_2/p_1$). In this case, more of $y_1$ should be produced and less of $y_2$ in order to maximize revenue. To achieve the same level of revenue as at point C while maintaining the same input and output combination, output of the firm would need to be expanded to point D. Hence, the revenue efficiency (RE(y,x,p)) is given by 0A/0D. Output allocative efficiency ($AE_O$(y,w,w)) is given by RE(y,x,w)/$TE_I$(y,x), or 0B/0D in Figure 3(b) (ibid).

*Figure 4: Input (a) and output (b) oriented efficiency measures*




*Source: Herrero I. and S. Pascoe (2002), Estimation of technical efficiency: a review of some of the stochastic frontier and DEA software, Volume 15 issue 1, Economics network, Department of Economics, University of Portsmouth*

One can understand from the discussion presented above, livestock water productivity can best be analyzed using the estimation of production frontier from a panel data on agricultural production collected over time across a reasonable sample size of farm households. Estimation of production frontier helps to determine gap between the potential and the actual water productivity and thus possible to formulate the appropriate intervention programme to improve water productivity.

Coming back to the practical case of this study, we know that the farmer's decision in the use of productive resources such as water is the result of rational behavior. In other words, the starting point for an analysis of any firm's production decision is the problem of minimizing the cost of producing a given level of output subject to technological constraints or maximizing profit given cost of production. Thus, least cost production is a necessary condition for the efficient allocation of resources (Graveel and Rees, 1992). To this end, WP will be evaluated and assessed using the equation

$$\text{WP} = \sum_{i=1}^{n} \frac{value\ of\ all\ outputs\ of\ the\ production\ sector\ S}{Depleted\ water\ in\ the\ production\ of\ S}$$

where *S* can be livestock, domestic or crop production, and *i* represents different products and services which runs from *1* up to *n*

Since water is an economic good (Perry and Seckler 1997), the WP should also be calculated using the value of depleted water to show how much resources, in terms of money, devoted to produce a one birr of livestock output. Further more, sometimes, small amount of water used in production may be produced at higher cost and to the contrary large amount of water can be produced at lower cost. Thus, to get the right indicator of the efficiency in the use of water, we may use the following formula

$$\text{WP} = \sum_{i=1}^{n} \frac{value\ of\ livestock\ products\ and\ services}{value\ of\ depleted\ water}$$

The value of depleted water can be estimated using the opportunity cost of water or using the sum of the money and real costs sacrificed to produce that water.

Finally, this magnitude of WP should be compared with the theoretical values or with WP that had been calculated in any other typical developing countries to evaluate our WP is whether good or not and to explore those constraints that are responsible for lower WP.

## III- Water accounting and factors affecting water productivity in agriculture

### 3.1- Water accounting model

Concepts to clearly distinguish between consumptive and non-consumptive uses, beneficial and non-beneficial uses, and reusable and non-reusable fractions of the nonconsumed water diverted into an irrigation system or subsystem were proposed by Allen *et al.* (1997) and Burt *et al*. (1997) [Pereira et al., 2002]. The objective to differentiate these concepts is to set alternative performance indicators that are much more relevant than "irrigation efficiency" when adopted in regional water management for the formulation of water conservation and water savings policies and measures. These concepts and indicators are easy to adapt and extend to non-irrigation water uses. Further more, the concepts are more useful for water resources planning and management under scarcity and should lead to less misinterpretation than the term "efficiency" (ibid).

According to Pereira et al., (2002), three water use fractions are considered:

a) the consumed fraction, consisting of the fraction of diverted water which is evaporated or incorporated in the product, or consumed in drinking and food, which is no longer available after the end use,
b) the reusable fraction, consisting of the fraction of diverted water which is not consumed when used for a given production process or service but which returns with appropriate quality to non degraded surface waters or ground-water and, therefore, can be used again, and
c) the non-reusable fraction, consisting of the fraction of diverted water which is not consumed when used for a given production process or service but which returns with poor quality or returns to degraded surface waters or saline ground-water and, therefore, cannot be used again. Each of the above fractions is then divided into two parts, corresponding respectively to the beneficial and the non-beneficial uses. Therefore, it is then easier to identify how water use could be improved, and how water savings should be oriented.

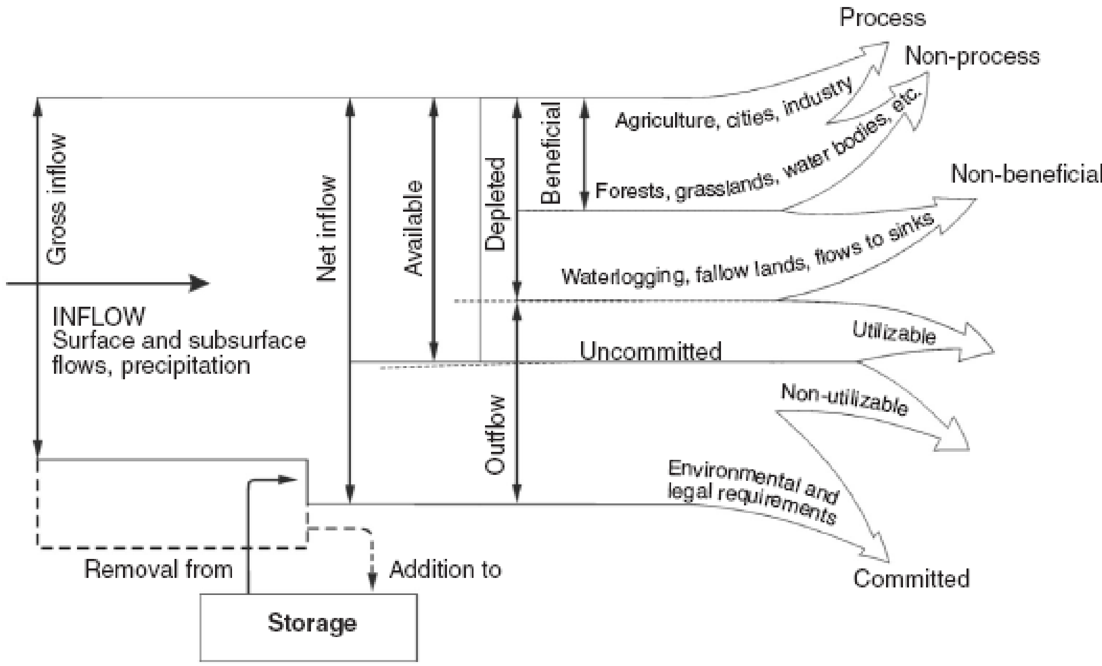
Based on the concepts mentioned above, Pereira et al., (2002) concluded that water losses are those corresponding to non-consumptive and non-reusable quantities of water used, which define the non-reusable fraction. However, in the case of saline environments, part of the water loss is beneficial to the crop and the soil because it is used for leaching of salts and, therefore this loss cannot be avoided. The non-consumptive but reusable quantities of water are in reality not lost because other users or the same system downstream can use them again, mainly when reuse facilities are available. This reusable fraction, like the non-reusable, may be due to poor or less than optimal management, but may be required by the production or service process under consideration. It is often considered as lost but in fact it is only a temporary loss to the system and cannot be considered a loss from a hydrological perspective or under the overall water resource economy. However, the size of the reusable fraction influences the cost of the system or sub-system operation and management and, moreover, it represents a non-necessary part of the demand, thus inducing negative impacts on the water allocation process and on the conservation of the resource (ibid).

To identify the different fractions of water mentioned above, proper analysis of water accounting should be done at different scales. Water accounting provides a means to generalize about water use across scales, and to understand the denominator of the water productivity better (Molden and Sakthivadivel, 1999 in Molden et al.,2003 ). Water accounting can be applied at all scales of interest, and requires the definition of a domain bounded in three-dimensional space and time. For example, at the field scale, this could be from the top of the plant canopy to the bottom of the root zone, bounded by the edges of the field, over a growing season. The task in water accounting is to estimate the flows across the boundaries of the domain during the specified time period (ibid). Molden et al.,(2003) states that at the field scale, water enters the domain by rain, by subsurface flows and, when irrigation is available, through irrigation supplies. Water is depleted[*] by the processes of growing plants: transpiration and evaporation. The remainder flows out of the domain as surface runoff or subsurface flows or is retained as soil-moisture storage. In estimating water productivity, we are interested in water inflows (rain plus irrigation, or just rainwater in rain-fed agriculture) and water depletion (evaporation and transpiration). The water accounting procedure classifies these inflow and outflow

[*] Depletion is when water is rendered unavailable for further use in the present hydrological cycle. This happens by evaporation, flows to sinks and incorporation into products. Water can also be considered depleted when it becomes too polluted for further use.

components into various water-accounting categories, as shown in figure 5 (and its elaboration is presented in Box1 below).

*Figure 5- Generalized water-accounting diagram, applicable to basin analysis and analysis at other scales*




*Source: Molden et al.,(2003), A Water-productivity Framework for Understanding and Action, International Water Management Institute, Colombo, Sri Lanka*

Box 1- water accounting definitions

-*Gross inflow* is the total amount of water flowing into the water-balance domain from precipitation and from surface and subsurface sources.
-*Net inflow* is the gross inflow plus any changes in storage.
-*Water depletion* is a use or removal of water from a water basin that renders it unavailable for further use. Water depletion is a key concept for water accounting, as interest is focused mostly on the productivity and the derived benefits per unit of water depleted. It is extremely important to distinguish water depletion from water diverted to a service or use, as not all water diverted to a use is depleted. Water is depleted by four generic processes:
i) Evaporation: water is vaporized from surfaces or transpired by plants.
ii) Flows to sinks: water flows into a sea, saline groundwater or other location where it is not readily or economically recovered for reuse.
iii) Pollution: water quality gets degraded to an extent where it is unfit for certain uses.
iv) Incorporation into a product: through an industrial or agricultural process, such as bottling water or incorporation of water into plant tissues.
-Process consumption is that amount of water diverted and depleted to produce an intended product.
-Non-process depletion occurs when water is depleted, but not by the process for which it was intended. Non-process depletion can be either beneficial or non-beneficial.
-Committed water is that part of the outflow from the water-balance domain that is committed to meet other uses, such as downstream environmental requirements or downstream water rights.
-Uncommitted outflow is water that is not depleted or committed and is therefore available for a use within the domain, but flows out of the domain due to lack of storage or sufficient operational measures. Uncommitted outflow can be classified as utilizable or non-utilizable. Outflow is utilizable if by improved management of existing facilities it could be used consumptively. Non-utilizable uncommitted outflow exists when the facilities are not sufficient to capture the otherwise utilizable outflow.
-Available water is the net inflow minus both the amount of water set aside for committed uses and the non-utilizable uncommitted outflow. It represents the amount of water available for use at the basin, service or use levels. Available water includes process and non-process depletion plus utilizable outflows.
-A closed basin is one where all available water is depleted.
-An open basin is one where there is still some uncommitted utilizable outflow.

In a fully committed basin, there are no uncommitted outflows. All inflowing water is committed to various uses.

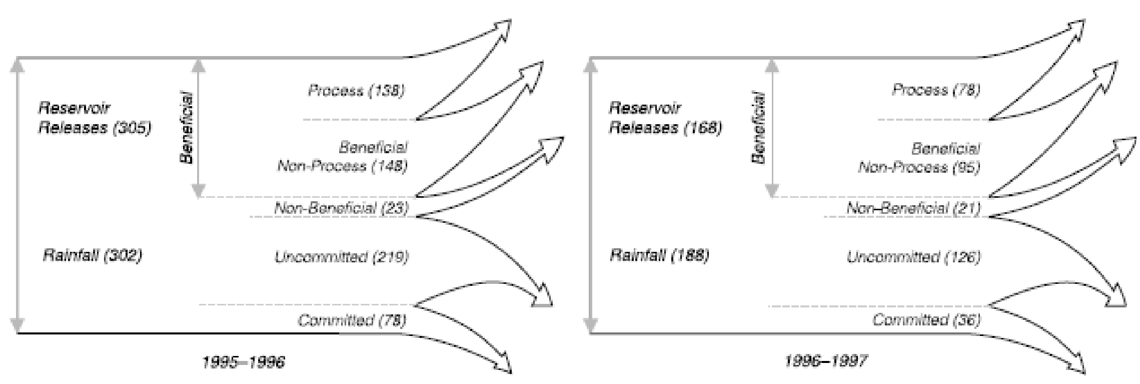
*Source: Molden et al.,(2003), A Water-productivity Framework for Understanding and Action, International Water Management Institute, Colombo, Sri Lanka*

Molden et al.,(2003) argue that we can generalize water accounting to any agricultural uses of water when the need arises in the process of water productivity analysis. For instance, if water is diverted and kept in ponds for fish, the surface evaporation from the pond is accounted for as water depleted by fisheries. If stream flows are maintained at minimum levels, restricting other uses, the amount of this water should also be considered as depleted by fisheries. In other cases, where fisheries arise because of the development of irrigation reservoirs, value is added to the water without additional depletion.

On the other hand, farmers in rain-fed arid areas, for example, are extremely concerned with capturing and doing the most with limited rainfall. Where an additional supply is available as supplemental irrigation, maximizing the output from a small amount of additional irrigation supply is normally highly productive. For irrigation farmers and system managers, the water supply is the bread and butter of the business. Water supplies, whether rainfall, supplemental irrigation or full irrigation supplies, are candidates for the denominator(ibid).

A case study by Bakker et al.,(eds), 1999 in Sri Lanka (*Kirindi Oya subbasin*) is presented here to show how the method of water accounting is related to water productivity. The case study took the Lunuganwehera reservoir is the Northern boundary (the reservoir itself is not included in the study) and the other boundaries coincide with the Kirindi Oya river basin boundaries. The accounting categories are derived from a water balance for the study period 1995-96 and 1996-97. Any change in the groundwater or the surface water storage is equal to the volume of rainfall plus Lunuganwehera reservoir releases minus the sum of evaporation and surface water outflows. The study group mentioned that since this amount of data was not available estimates had to be made to perform the analysis. While the change in storage over a one-year time period was assumed to be negligible, rainfall and reservoir releases were measured by the study group.

*Figure 6- Water accounting for Kirindi Oya subbasin, 1995–1996 and 1996–1997*




Source: Bakker et al.,(eds), 1999. Multiple uses of water in irrigated areas: A case study from Sri Lanka. SWIM Paper 8. Colombo, Sri Lanka: International Water Management Institute.

For 1995–1996, the depleted fraction (DF), i.e., the amount depleted divided by the total inflow, was 0.51. This indicates that 51 percent of the water entering the area is depleted. The process fraction of depleted water, defined as the process depletion divided by total depletion, is 0.45. This indicates that only 45 percent of the amount of water that was depleted went to intended processes and this shows scope for considerable water savings. Most of these savings could be obtained by decreasing drainage outflow to the ocean. The DF can vary from year to year depending on the volume of the total inflow and/or the depleted fraction. For instance, the DF for 1996-97 is 22% which is lower than the 1995-96 DF (=51%). Assuming the DF is linearly related with the volume of total output in agriculture and all other things remain constant, the production in 1996-97 is lower as compared to the production in 1995-96. This means that the value of the numerator in the water productivity equation 1996-97 is less than that of the 1995-96 (assuming equal values in the denominators of the two periods), then the value of WP of the 1996-97 falls down as compared to the previous period. From this we can understand that water productivity is dependent on the effectiveness of water shed (or basin) management and/or to the extent we can influence the volume of water inflow, process, not process fraction or any of the elements of water accounting model.

### 3.2- Factors affecting water productivity

Agricultural productivity differences for the same type and quantity/quality input use is always the case due to differences in environmental, agronomic, social and economic conditions of the different localities (Kijne et al., 2000). According to this source, for instance periodic flooding is common in rain-fed ecosystems, especially on soils with poor drainage which can seriously reduce crop yields. Crop yields are affected by abiotic stresses, e.g., imposed by the salinity of the irrigation water or salts present in the soil. Flooding and water logging can also lead to the salinization of the soil underlain by saline groundwater. Salinity usually arises from the use of poor-quality irrigation and from seawater intrusion in coastal areas.

The types of plant breeding plays an important role in water productivity. This is so because improved verities increase yields together with the reduction in crop-growth duration. Drought escape and increasing drought tolerance have been identified as important strategies for increasing water productivity. For instance, the modern 'IRRI verities' developed as part of the Green Revolution have about a threefold increase in water productivity compared with the traditional varieties (Tuong 1999 in Kijne et al., 2000). Water evaporation and transpiration from weeds is also influence water productivity through increasing non-beneficial water depletion. Thus, plant breeding for early shading will contribute to reducing evaporation while improved weeding and timely application of weed killer reduces transpiration from weeds (ibid).

According to Tuong (1999); Rockstrom et al. (2002), there is an almost linear relation between yield and water productivity per unit water transpired. Hence integrated crop-and resources–management practices that increase yield will effectively increase water productivity (WP). Improved nutrient management can also enhance WP, however, there are uncertainties about what actually happens with agro-chemicals and fertilizers when applied to the soil surface. If the fertilizers are to a large extent leached from the root zone it is obviously a waste of money and labor and also result in bad environmental consequences since nitrogen is a potential pollutant though it is an essential plant nutrient- any way WP may fall down (ibid).

Many cultural practices, such as row spacing, the use of mulches and plant residues have the potential to increase WP through their effects on partitioning evapotranspiration between evaporation and transpiration. Irrigation methods also have the effect on WP via evaporation. Burt et al. (2001) reported that drip irrigation reduced evaporation compared with sprinkler and furrow irrigation. More water is thus available for transpiration and higher crop yield is expected from drip irrigation. With regard to grazing land management, WP would be very low in heavily grazed areas with little vegetative cover. For example, Sonder et al., 2005 and Palmer 2000 cited in Peden et al., 2005 (b), suggest that evaporation can be up to six times more than transpiration. That means since transpiration is not the only form of depleted water associated with feed production, the denominator will be very high or the numerator will be very low in the WP equation and hence WP would be very low.

Water is used by the herbivore as a medium for physical and chemical energy transfer, namely for evaporative cooling and intermediate metabolism. There are three sources of water for the animals: 1) drinking water, 2) water contained in feds and 3) metabolic water. Most of the water that is utilized by the animal's body is ingested either as drinking water or as a component of the feed (McCornick et al., 2003 in Yusuf et al., 2004). Livestock water consumption depends on a number of physiological and environmental conditions such as : the type and size of the animal, type of feed (dry, silage or lush pasture) and salt ingested, physiological state (lactating, pregnant or growing), activity level, water quality (palatability and salt content), temperature and animal's genetic adaptation to its environment. Further more, the water requirement of domestic animals varies between species, between breeds or varieties within species and between individuals within breeds (ibid).

Water productivity of livestock may be high or low depending on the context within which livestock production is evaluated. Livestock produced solely with irrigated forage and grain crops may be very inefficient in terms of water consumed for food produced. However, 'cut-and-carry' and grazing production relying on consumption of crop residues and tree fodder can be very efficient since the water used for production would have been used with or without livestock feeding on it. Further more, much of the water consumed by livestock is released into the soil as urine providing soil nutrients and soil moisture. So, it should be clear that livestock production could be viewed as either one of the most efficient or inefficient means of producing food for people depending on the system in which the livestock are raised (Peden et al. 2005). Water productivity also varies according to the geographic scale being considered and depends largely on the degree to which water is depleted or available to other users or ecosystem services (ibid).

Water productivity is also affected by livestock and water management. According to ILRI (2002), human health is a fundamental aspect of poverty. Water borne human illnesses often arise from contamination of domestic water by poorly managed livestock. For example, Cryptosporidum, a parasite whose oocysts are common in livestock, has been associated with various outbreaks of human illness in recent years and thought the impact of HIV/AIDS (FAO 1997 in Peden et al. 2005). From this we can understand that a certain system of livestock and water management can affect water productivity via increasing the cost of livestock production (illness) or decreasing the cost (absence of illness). Clean water is also essential to ensure hygiene in processing dairy and meat products. Without quality water food safety is jeopardized and market opportunities are lost, implying water productivity is hampered. In general, consideration of externality in evaluating water productivity is very important to improve the welfare of the community.

Agricultural water productivity is also highly correlated with land degradation which can be caused, among others, by market and government failures. Land degradation is defined as the depletion of soil quality. At the same time, the quality of the soil present on a farmer's field in any one production period is a determinant of the yield outcomes. Generally, more highly degraded lands result in lower productivity, although the impacts vary across production conditions and the production technologies employed. Lower productivity can be due either to decreasing yields or increased production costs associated with decreased input efficiency. Land degradation may also result in greater yield variability, and thus greater costs to risk-averse farmers (Bariber, 1998).

Many empirical studies have reported the immensity of environmental degradation in Ethiopia. Reducing environmental degradation is a major challenge especially in the Ethiopian highlands. Land degradation, especially soil erosion (averaging 42 t/ha per year on cultivated lands (Hurni 1988)), low and declining soil fertility, soil moisture stress and deforestation are critical problems contributing to low agricultural productivity (which is reflected in cereal yields averaging less than one tone per hectare), poverty and food insecurity in these areas (Fistum et al 1999; in Pender et al 2000).

FAO (1986 in Bekele and Holden 2000) estimates that 50% of the highlands are significantly eroded, of which 25% are seriously eroded, and 4% have reached a point of no return. Hence, soil erosion induced productivity decline is estimated to average 2.2% per annum from that of the 1985 level. Similarly, the Soil Conservation Research Project had also estimated an average soil loss of 42 t/ha/year on cultivated lands and a maximum of 300-400 t/ha/year in highly erodible and intensively cereal cultivated fields (EPA, 2003 in Danieal). Nearly three decades ago, the Ethiopian Highland Reclamation Study estimated that about half of arable lands in the highlands have been eroded from moderately to seriously levels (Constable, 1985). By now, this figure might have reached a much higher level, where human population (which is believed to be the underlying factor) has increased by more than 65% since then (ibid).

In Ethiopia, rural communities depend primarily on common property resources for irrigation water, construction material, fuelwood, and grazing land. Population pressure, market and government failures, and the absence or ineffectiveness of use regulations of common property resources has resulted in severe degradation of the resources. Perhaps as a result, Ethiopia has been identified as the country with the most environmental problems in the Sahel belt (Hurni, 1985 in Tesfay et.al, 2003).

Market failures, according to Deng (2000), "induce an excessive amount of land degradation" and occur because of the market is unable to deal with: a) externalities, b) public goods and "bads," c) risk markets, d) future markets, and e) private versus social rationality. Optimal government intervention is believed to reduce some of the undesired effects of market failures. However, government failures aggravate the problem of land degradation. There are eight sub categories of government failures. Bojö (1991 in Deng 2000) points out that "many failures are derived from the fundamental problem that the government (political leaders and bureaucracy) is not maximizing a social welfare function, but rather a more narrow function of self-interest". Hence, land degradation is due to failures in: a) property rights definition and enforcement, b) population policy, c) price policy, d) international trade policy, e) tax policy, f) political elite attitude toward sustainable patterns of resource use, g) public investment with respect to natural resource management, and h) public information and democratic decision making process.

If we take the case of property right, extensive empirical evidence suggests that access to, and the quality of, environmental resources play a crucial role in the ability of the poor to sustain their livelihoods. The poor depend on natural resources, that they themselves own, that the community owns, or that are open access property for growing food, grazing land, wild food, fish, fuel, fodder and other resources. These resources may be families' primary source of livelihood or they may supplement daily needs or income. Available evidence suggests that the poor are much more dependent on common property resources for their livelihood than the rich. One survey of 82 villages in India found that the poor obtain 66 to 84 percent of fodder from common property resources (CPRs) in some states. CPRs also provided 14 to 23 percent of the income of the poor and approximately 137 to 196 days of employment per poor households (Deng 2000). Since the poor often acquire a significant part of their income and consumption from natural and community resources, their ability to meet their daily needs is also affected when the quality of natural resources degrades. For instance, when the quality of water in nearby streams deteriorates, the poor are more adversely affected than wealthier households because they may not have resources to take adaptive actions (for instance, boiling the water). Hence, institutional mechanisms that govern access to these resources play an important role in maintaining their productivity and in ensuring equitable use (ibid).

## IV- Some evidences about water harvesting and water use in rural Ethiopia

Water harvesting is ideally suited to arid and semi-arid areas where rain-fed crops cannot be grown with any certainty because the rainfall is both unreliable and highly variable. The rainy season in these arid and semi-arid areas is also often short with no assurance of when it will start and finish and there may be frequent long dry spells (FAO 1993 in Puskur et al., 2005). Thus, this inadequacy of moisture will surely lead to the reduction of plant growth. Therefore, irrigation from harvested water is used as a supplement to in order to combat periods of moisture stress so as to fulfill the crop moisture requirement and increase the production.

The promotion and application of rainwater-harvesting techniques as alternative interventions to address water scarcity in Ethiopia was started through government-initiated soil and water conservation programmes (Meselech 2005). It was started as a response to the 1971–74 drought with the introduction of food-for-work programmes, which were intended to generate employment opportunities to the people affected by the drought (ibid). The earlier rainwater harvesting activities included, among others, construction of ponds, micro-dams, bunds, and terraces in most drought-affected areas in Tigray, Wello and Hararghe regions (Kebede 1995). Non-governmental organisations (NGOs) involved in Integrated Rural Development Projects and the water sector in many parts of the country also undertake rainwater-harvesting interventions. These interventions include conservation of rainwater by making use of physical structures and rainwater harvesting for domestic use and irrigation purposes through pond and micro-dam construction and roof catchment schemes.

For Ethiopia, much of whose river waters are carried away across the borders by trans-boundary rivers, the issue of augmenting the available water resources to meet the socio-economic needs of its people becomes a necessity and timely in light of two major reasons (Meselech 2005). Firstly, attainment of food security through enhancing the productivity of the agriculture sector, with a primary emphasis on building the productive capacity of the smallholder farmers, has been an overriding objective of the Government's Poverty Reduction and Food Security Strategies. In line with this, the Ministry of Agriculture has been making some efforts towards the development and promotion of rainwater-harvesting technologies as part of its extension programme. Secondly, based on the current trend of population growth, by the year 2025, Ethiopia will have nearly 120 million people and the per capita water availability will drop to about 947 $m^3$/person per year (Falkenmark et al. 1990; UNEP/IETC 1998). This situation, according to Falkenmark's (1990) definition of water scarcity, will make Ethiopia among the eight African countries facing water scarcity by 2025 (UNEP/IETC 1998 in Meselech 2005).

The above facts strongly support the need to focus on development and promotion of rainwater-harvesting technologies as one of the alternatives to enhance water availability for different uses including domestic water supply, sanitation and food production. Accordingly, the current government of Ethiopia has launched the new water harvesting programme to realize the efforts towards food security in rural Ethiopia since 2003.

To evaluate the performance of small-scale household level water harvesting structures that has been developed since 2003 in rural Ethiopia, different studies have been conducted by different organizations. The sample survey conducted by Ethiopian Development Research Institute (EDRI 2005) covering 2033 households (hhs) all over the country, reveal that out of the total (2033) water harvesting structures, pond, hand dug well, and others constitute 76%, 15% and 9% respectively. The main activities the water used for are, according to importance, horticulture, crop production, drinking for human, drinking for livestock, forage production, peripheral crops, Bee keeping and others.

Households use different water sources for their domestic use. According to EDRI (2005), the amount of hhs that use pipe from nearby towns are 30%, stream (27%), well (15%), river (14%), and pond (14%). This shows that some of the hhs though they have their own water harvesting structures, they still get water for domestic use from rivers and streams. This may be due to insufficient amount of water was harvested by hhs for various purposes. As a result about 81% of the total hhs covered by the survey, walked more than one hour and 30% out of this 81% walked more than two hours to fetch water from rivers and streams (EDRI, 2005).

With regard to livestock holding, the majority (52%) of the hhs own one livestock, the rest 30% own two livestock and the remaining 18% own three and more livestock. Similarly, 55% of the hhs own land less than one ha and 20% own more than one ha but less than 2.5 ha, the remaining 25% own land 2.5 ha and more (EDRI 2005). These statistics imply that most of the hhs in water harvested areas are very poor since low level of asset holdings such as livestock and land are one of the manifestation of poverty in many developing countries.

Another study was also conducted by Oromia Irrigation Development Authority (OIDA, 2004) to evaluate the performance of water harvesting activities that were developed in 2003 in Oromia Region.

OIDA shows that in 56 districts (Woredas) of 9 zones in Oromia Region, out of the 8609 beneficiary households (hhs) covered by the survey, only 4614 hhs (54%) are found producing vegetables, cereals, chat and other crops on 256 hectares of their garden plot and obtained about 20115 quintals of yield. The gross income of these beneficiary hhs was estimated to be about 2.5 million Birr[†] from their garden plot and water sell (the share of water sell is birr 31312 or 1.3% out of the total). The remaining 46% hhs, though they try to produce various horticultures and crops using the water as supplemental irrigation, they use much of the stored water for domestic uses (drinking, cooking, bathing), livestock drinking, fattening, nursery development and for house construction purposes. Out of the 54% of hhs that primarily use the stored water to produce different agricultural outputs, only 751 hhs (9% of the total) are using the entire water as supplemental irrigation for crop production. That means, in general, 91% of the hhs covered by the survey use the water for crop, livestock and domestic uses simultaneously.

*Table 1- Water used from rain water harvested for other purposes in addition to vegetable and crop production by number of households (hhs)*

| No | Water used for | No. of hhs | Valid % |
|---|---|---|---|
| 1 | Domestic use* (A) | 559 | 7 |
| 2 | House construction (B) | 68 | 0.8 |
| 3 | Livestock (C) | 1442 | 17.7 |
| 4 | Nursery (D) | 293 | 3.6 |
| 5 | Combination of A&B | 103 | 1.3 |
| 6 | A&C | 2590 | 31.8 |
| 7 | A&D | 129 | 1.6 |
| 8 | B&C | 325 | 4 |
| 9 | B&D | 32 | 0.4 |
| 10 | C&D | 385 | 4.7 |
| 11 | ABC | 569 | 7 |
| 12 | ABD | 26 | 0.3 |
| 13 | BCD | 217 | 2.7 |
| 14 | ACD | 487 | 6 |
| 15 | ABCD | 160 | 2 |
| 16 | Only for crop | 751 | 9 |
| | Total | 8142 | 100 |
| | Not responding | 467 | |
| | Grand total | 8609 | |

* Domestic use represents water used for drinking, cooking, bathing, and cloth Washing

*Source: Oromia Irrigation Development Authority-OIDA (2004), Evaluation report on benefits of water harvesting schemes implemented in 2003 (1995 E.C) in nine zones of Oromia region.*

One can understand from the above table that water has being used for many purposes though the water structures were developed only for irrigation farming. The

[†] Birr is Ethiopian currency and the current exchange rate is 1 U.S. Dollar = birr 8.5

total number of hhs that use water for livestock (18%), domestic use (7%) and the combination of the two (A&B) constitute a significant proportion, i.e.,57%. That means, the majority of the hhs use the water in addition to producing vegetables and crops, for the two (domestic use and for livestock) most important activities. Hence, systematizing of MUS would be mandatory to improve water productivity of those water structures.

In table 1, it was tried to show multi-use water services among beneficial hhs from harvested water schemes in Oromia region. It should be noted that, those water services listed above are additional benefits hhs were getting in addition to vegetables and crop production. The following table shows that income generated by those hhs that primarily use the water resource for vegetables and crop cultivations.

*Table 2-Summary of income generated at household (hh) level(2003)*

| No | Type of technology | Beneficial hhs | Quantity of Harvested water $m^3$ | Area irrigated (ha) | Yield (qt) | Income (birr) | Water sale | | Total income Birr |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | hh | Birr | |
| 1 | Pond | 3,215 | 353,650 | 118.0235 | 6,437 | 1,045,063 | 80 | 17,478 | 1,062,541 |
| 2 | Hand dug well | 1,139 | - | 128.4632 | 8,924 | 1,322,744 | 23 | 11,945 | 1,334,689 |
| 3 | Tanker | 260 | 15,600 | 9.9103 | 4,754 | 77,293 | 14 | 1,889 | 79,182 |
| Total | | 4,614 | 369,250* | 256.397 | 20,116 | 2,445,100 | 117 | 31,312 | 2,476,412 |

* the sum of quantity of water from the two technologies: pond and tanker.

*Source: Oromia Irrigation Development Authority-OIDA (2004), Evaluation report on benefits of water harvesting schemes implemented in 2003 (1995 E.C) in nine zones of Oromia region.*

In table 2, the amount of water harvested using each technology is calculated based on the guideline prepared by Rural Development Bureau of Oromia to introduce water harvesting technologies into the region. Of course this guideline is adopted from the Federal Government of the country prepared for implementing the programme and strategy of water harvesting technologies to promote food security in rural Ethiopia. According to this document, each household has its own water harvesting structure and each pond has a carrying capacity of 60-120$m^3$ of water. Among these, much of the ponds have the carrying capacity of 120$m^3$ of water. According to experts in OIDA, the average water holding capacity of a pond is calculated to be 110$m^3$ of water. Thus, 110$m^3$ multiplied by the total number of ponds (i.e., 3215) gives an indication of the amount of water (353650 $m^3$) harvested by all ponds. Similarly, the quantity of water harvested by underground tankers is 15600$m^3$ (=number of tankers, i.e., 260 multiplied by the carrying capacity of a tanker which is 60$m^3$). However, estimating the quantity of water produced by hand dug wells was very difficult because, these wells naturally regenerate water so that they don't supply a fixed amount of water rather they provide water continuously.

After deducting water used for livestock (22%), domestic use (8%) and waste water (10%), the crop water productivity at gross value of output ($CWP_G$) from pond, tanker and the sum of the two technologies together are Birr 2.46, 4.13 and 2.53 per $m^3$ of water respectively.

According to OIDA (2004), water harvesting activities also contribute to other benefits to hhs, such as promoting vegetables feeding habit and change of working habit. As water available for various purposes in the locality, labor would be fully employed as this water creates opportunity to work for much of the household members. As a result, it was observed that, family members would share work among them selves, planning their time, and get used to work on holidays. Water supply from the harvested water for human and livestock uses, regardless of its purity and potability, was also found very important benefit of this technology especially in low land areas of the region (ibid).

OIDA (2004), also found that hhs located near to markets are encouraged to produce marketable vegetables and crops where as those hhs that don't have market access are inclined to use much of the stored water for domestic purposes and for livestock. With regard to environment, the same survey suggests that recharge of ground water was identified as the positive environmental impact in some areas where water harvesting technologies like pond are widely used while negative environmental impact such as depletion of ground water resulted in the areas where hand dug wells are found concentrated in a relatively small area.

## V- Empirical analysis of harvested water productivity in rural Oromia and Southern (SNNP) Regions

### 5.1- Source of data

The empirical analysis is based upon the census data obtained from the base line survey on water harvesting pilot projects conducted in July 2006 by Saasakawa Global-2000 in Oromia and SNNPR Regions. The pilot projects are sponsored by SG-2000 which is an established NGO in Africa aiming to ensure food security in poor developing countries. In 2005, SG-2000 had about 57 water harvesting (WH) pilot projects in Oromia (84.2%) and SNNPR (15.8%). In Oromia, administrative Zones such as West Showa, East Showa and West Arsi and in SNNPR one Zone ,i.e., Alaba were included during the survey. This base line survey has covered all WH projects developed by SG-2000 in 2003 in the two regions.

### 5.2- Description of data

Each household (hh) covered by the survey has its own WH structure in its homestead. The average size of a hh is 7.95 with the minimum and maximum of 2 and 15 respectively. The majority (55%) of beneficial hh own land 1.75 ha and less while the minimum and the maximum land holding are 0.25 and 7 ha respectively. Since almost all hhs use the significant proportion of their land for crop cultivation, abut 67% of beneficial hhs have grazing land less than 0.25 ha and the remaining own 0.5-1.5 ha. In the survey area there is land market in which about 35 hhs (61.4%) land rented in and very few 5 hhs (0.09%) land rented out.

With regard to irrigation, much of the hhs (77%) are practicing it and irrigate their own land ranging from 0.03 to 1.5 ha. Almost all beneficial hhs have their own livestock with the minimum of one and the maximum of 39.

*Table 3 - Population of livestock in the study area*

| Type of animal | Number of hhs | Number of livestock owned by households | | | | |
|---|---|---|---|---|---|---|
| | | Minimum | Maximum | Sum | Mean | Std. Deviation |
| Draft Oxen | 49 | 1 | 10 | 131 | 2.67 | 1.63 |
| Cows- local | 40 | 1 | 7 | 83 | 2.08 | 1.37 |
| Cows- crossbred | 21 | 1 | 3 | 30 | 1.43 | 0.60 |
| Heifer- local bred | 26 | 1 | 5 | 48 | 1.85 | 1.32 |
| Heifer -cross bred | 7 | 1 | 2 | 8 | 1.14 | 0.38 |
| Bull | 18 | 1 | 6 | 28 | 1.56 | 1.20 |
| Sheep | 15 | 1 | 10 | 77 | 5.13 | 2.47 |
| Goats | 23 | 1 | 20 | 124 | 5.39 | 4.69 |
| Horses | 1 | 1 | 1 | 1 | 1.00 | - |
| Donkey | 41 | 1 | 7 | 90 | 2.20 | 1.27 |
| Mules | 1 | 1 | 1 | 1 | 1.00 | - |

*Source: SG-2000 (2006), Baseline survey*

The average size of livestock holding is 10.6 with standard deviation of 7.5. Most hhs (72%) in the study areas use open grazing as the main source of cattle feed while only 11% use mostly stall feeding. Animal fattening is a common practice in some of the areas covered by the survey. About 30% of the hhs fatten oxen, cow and sheep. More over, 60% of the hhs did have milk cow during the survey period and among which 61% use modern feeding for their milk cows such as flour bran and oil cakes which are the by-products of flour and oil mills.

When we look at the distribution of the main sources of drinking water for the family, number of hhs that use communally owned pipe water-Birka/Bono (58%), river (23%), pipe water from the nearest town (14%), pond (3.5%) and spring (1.8%). During the survey, respondents were asked whether they got any change due to the introduction of those WH technologies in their homesteads. The following table presents the summery of their responses.

*Table 4- change of some indicators after the implementation of WH technologies*

| No | Questions forwarded to respondents | responses | | | |
|---|---|---|---|---|---|
| | | Positive change | | no change | |
| | | No. | Valid % | No. | Valid % |
| 1 | Availability of water for domestic use | 37 | 75.5 | 12 | 24.5 |
| 2 | Availability of water for livestock use | 33 | 67.3 | 16 | 32.7 |
| 3 | Availability of water for garden crops | 37 | 74 | 13 | 26 |
| 4 | Nutritional status of children | 32 | 74.4 | 11 | 25.6 |
| 5 | Nutritional status of all hh members | 38 | 86.4 | 6 | 13.6 |
| 6 | Health situation of hh members* | 38 | 84.4 | 6 | 13.3 |
| 7 | Sanitary situation of the hh members | 44 | 91.7 | 4 | 8.3 |
| 8 | Schooling children | 29 | 61.7 | 18 | 38.3 |
| 9 | Hh dietary needs | 37 | 82.2 | 8 | 17.8 |
| 10 | Size of land cultivated* | 15 | 31.3 | 31 | 64.6 |

* the health situation of one hh (2.2%) and the size of land cultivated of two hhs (4.2%) got worse after the implementation of the project.

*Source: SG-2000 (July 2006), Base line survey*

Almost all in the cases (except size of land cultivated) responses are affirmative concerning the changes these WH technologies bring about to the hhs. In other words, the availability of water does improve the welfare of the communities in terms of the indicators listed in table 3. For instance, 75.5% of the hhs can easily get water for domestic use in their homestead with out traveling long distance to fetch water for hh production such as drinking, cooking, cloth washing, etc.

Having discussed the socio-economic conditions of the study areas and the performance of WH structures, now we turn to the major objective of this study, i.,e., the analysis of water productivity. Hence, in the following sections livestock, domestic use and crop water productivity will be discussed separately and finally comparison can be done among these three sectors of agricultural activity.

### 5.3- Analysis of water productivity

In any economic activity, to produce a certain output we usually use a combinations of inputs among which water is one of them. So, to measure the productivity of any input used in production, we calculate the value of total output per a unit of input used in that production process. Thus, in general, water productivity can be calculated using the formula

$$WP = \frac{\text{the sum of values of all outputs produced using water as input}}{\text{quantity of water depleted in the production}}$$

The numerator of WP equation can be put in terms of the gross value of output (GVO) or net value of output (NVO) depending on the availability of data, though, WP calculated using NVO gives better picture of the net gain from a unit of water in production.

If P, Q and C stand for the price of a product, the quantity of the product (or yield), and total cost of production respectively, then WP at GVO and at NVO are

$$WP_G = \frac{PQ}{W} \text{ and } WP_N = \frac{PQ - C}{W}$$

Where PQ is the value of output and W= quantity of depleted water in production. The numerator in $WP_N$ is the value added or net output of an activity from the given quantity of water.

Since each variable of the numerators can be whether endogenous or exogenous for the producer, then the value of the numerators in both $WP_G$ and $WP_N$ are determined by many factors. That means, as literatures of economics show that if P is exogenous to the producer and determined in the market (of course P is determined by many factors), Q is endogenous to the producer and hence the production function will be $Q = f(X_1, ..., X_n)$, where $X_i$ is the quantity of various factors of production, such as labor, capital, technological advancement, etc. In short, the production function shows the technical relationship between different kinds of inputs. Similarly, cost of production (C) is also the function of some other variables which, in turn, determine the magnitude of WP. The cost function is, therefore, $C = f(Z_1, ..., Z_n)$ where Zi represents variables such as price of factors of production, availability of labor, capital, technological advancement, etc. Further more, the amount of depleted water (W) is also the function of many agro ecological and biotechnological factors such as evaporation, transpiration, crop type & species, soil type, and so on in the case of crop water productivity (CWP); and the size & type of animal, the type & amount of feed intake, and so forth in the case of livestock water productivity (LWP).

The matimatical relationships of variables in the WP equation states that, assume all other things are constant, as P and/or Q increase, WP rises up but as C increases WP would fall down. Further more, as W increases (due to much waste of water or inefficiency in the use of water),WP would decrease.

In general, these system of functions (production function, cost function, etc.) imply that, WP can be affected by many exogenous and endogenous factors which are very important to determine the magnitude of it. Therefore, the analysis of WP should go beyond the simple calculation of WP equation so as to identify the possible constraints and to forward the alternative solutions to improve WP of a certain activity. Based on the above formula of WP, estimations of livestock, domestic use and crop WP are presented separately as follows.

### 5.3.1- Livestock water productivity

Livestock water productivity (LWP) can be defined as the sum of beneficial outputs of livestock per total depleted and degraded water in livestock production. Depleted water is the mount of water which is used for feed production, washing, drinking and barn management. Degraded water, on the other hand, is contaminated water, i.e., water is not in use due to mix with feaces and other adulteries (Girma et al., 2006). In this study, the amount of depleted water includes only water contained in feed (residue and grass) and drinking while water used for animal washing, barn management and degraded water are not included due to absence of data.

The formula used to calculate LWP is

$$LWP = \sum_{i=1}^{n} \frac{value\ of\ livestock\ products\ and\ services}{Depleted\ water}$$

, where *i* represents different livestock products and services which runs from *1* up to *n.*

The numerator of LWP is the sum of the values of the product and services of farm animals such as milk, meat, hides & skin, manure, animal power (plowing & trashing) and transport. The amount of water depleted to produce these outputs and the quantities of various outputs that can be produced from the given population of livestock are calculated based on the parameters estimated by Asrat, et. al.,(2006). Data on the number of livestock of the beneficiary hhs in the study areas are obtained from SG-2000 base line survey.

*Table 5- Quantity and value (birr) of Livestock products produced per year*

| outputs | Type of animal | | | | | Sum |
|---|---|---|---|---|---|---|
| | Cattle | Sheep & Goat | Horse | Donkey | Mule | |
| No | 328 | 201 | 1 | 90 | 1 | 621 |
| TLU | 236.16 | 20.10 | 0.80 | 37.80 | 0.70 | 295.56 |
| Milk-liter | 160,290 | - | - | - | - | 160,290 |
| value | 247,851 | - | - | - | - | 247,851 |
| Meat-kg | 1,818.43 | 693.45 | - | - | - | 2,511.88 |
| Value | 28,603.94 | 12,482.10 | - | - | - | 41,086.04 |
| Hides-No<br>value | 23.62<br>1,889.28 | -<br>- | -<br>- | -<br>- | -<br>- | 23.62<br>1,889.28 |
| Skin-No<br>value | -<br>- | 69.35<br>1,560.26 | -<br>- | -<br>- | -<br>- | 69.35<br>1,560.26 |
| Manure-ton<br>value | 271.71 | 27.53 | | 34,449.11* | | 34,748.35<br>18,069,146.27 |
| Plowing-value | 286,200 | - | - | - | - | 286,200 |
| Trashing-value | 95,400 | - | - | - | - | 95,400 |
| Animal transport-value | - | - | | 116,568* | | 116,568 |

** include the values of manure and transport from horse and mule*

*Source: own calculation*

To quantify the denominator of the LWP equation, the crop water requirement (CWR) parameters are also adopted from Asrat et. al.(2006). According to this source, the CWR from crop residues and grass for 1 TLU of livestock are 135.5031179 and 1557.339587 $m^3$ per year respectively. The parameters to calculate livestock watering, on the other hand, are adopted from Pallas 1986 in Peden et.al.,(2005). According to Pallas (1986), the voluntary daily water intake (litter/TLU) in dry season with average temperature of $27^0$c of the area are cattle (27.1), sheep (40), goat (40), camel (21.9), and donkey (27.4).

*Table 6- Water intake by animal type in the study area*

| Type of animal | No | TLU* | Water intake by animals ($m^3$/year) | | |
|---|---|---|---|---|---|
| | | | From residue+grass+drinking | From grass+drinking | From drinking only |
| Cattle | 328 | 236.16 | 402,124.11 | 370,123.69 | 2,342.38 |
| Sheep & Goat | 201 | 20.10 | 34,320.40 | 31,596.79 | 294.26 |
| Horse | 1 | 0.80 | 1,362.30 | 1,253.89 | 8.02 |
| Donkey | 90 | 37.80 | 64,368.53 | 59,246.50 | 379.07 |
| Mule | 1 | 0.70 | 1,192.01 | 1,097.16 | 7.02 |
| Sum | | 295.56 | 503,367.35 | 463,318.05 | 3,030.76 |

** 1TLU = 250 kg. The mean live weight of cattle=180 kg, sheep & goat each = 25 kg, donkey = 105 kg (Anonymous in Peden 2005).*

*Source: own calculation*

The assumptions and/or parameters used to calculate the numerator of the LWP-quantities of livestock products and services that could be produced annually in the given area and their prices are attached in Annex 1.

Based up on the information indicated above, the LWP at the gross value of output (GVO) in the study areas is found to be birr 37.47 per $m^3$ of water.

LWP = Birr 18,859,700.85/503,367.35 $m^3$ = Birr 37.47/$m^3$ of water.

Economists are, most of the time, interested in quantifying productivity in terms of the value of the resource sacrificed to produce the given level of output. This method of valuing the resource is very important to determine the opportunity cost of the resource in alternative uses. In our case since water is an economic good (Perry and Seckler, 1997), the LWP can also be calculated using the value of depleted water to show how much resources, in terms of money, devoted to produce one birr of livestock output. Further more, sometimes, small amount of water used in production may be produced at higher cost and to the contrary large amount of water can be produced at lower cost. In other words, valuation of water becomes more important if there is variation of water prices from place to place. Thus, to take into consideration the value of the resource devoted in production and hence to get the right indicator of the efficiency in the use of water, we may use the following formula

$$LWP_m = \sum_{i=1}^{n} \frac{value\ of\ livestock\ products\ and\ services}{value\ of\ depleted\ water}$$

The value of depleted water can be estimated using the opportunity cost of water or using the sum of the money and real costs sacrificed to produce that water. Alternatively, if there is market price for this water, this price can be used to value that water. Accordingly, the author of this study is informed that in some of the study areas water is sold and bought at the price of birr 0.50/Jerican (one Jerican = 20 liters of water). If we take this market price of water,i.e., birr 0.025/liter, then the value of the depleted water would be birr 12.6 million and $LWP_m$ at GVO becomes birr 1.5/birr of water. That means, one birr of water produces birr 1.5 of livestock products. According to CSA (2005), the average price of water in Oromia region is birr 7.69/m3 or birr 0.00769/lietr. In most parts of Ethiopia, however, the price of water is believed to be highly subsidized. For instance, MOFED (1998) states that water tariffs in urban Ethiopia only cover just about 50% of the costs of providing water and sewage services. Hence, if we make double this birr 7.69/m3, we can get the relatively true price of water to be birr 0.01538/lietr and the $LWP_m$ becomes birr 2.44/birr of water (=birr18,859,700.85/7,741,789.84m3).

It is recalled that the CWR of residues and grass is one component of the denominator of LWP. However, the CWR of residues is usually counted in the estimation of crop water productivity (CWP) and hence to avoid double counting the LWP should be calculated by deducting the CWR of residues as well as the CWR of grass (since grass is rain fed) in the denominator of LWP. Therefore, the LWP which is net of CWR of residues and grass will be birr 6,222.76/m3 (=birr 18,859,700.85/3,030.76 m3) of water. Here, the depleted water (3,030.76 m3) is that amount of water which is used only for watering livestock.

One can argue that even if grass in the study areas are rain fed, it has an opportunity cost in the sense that the land on which the grass grown can be used for other purposes. Hence, the better indicator of LWP would be the one which excludes only CWR from residues. Then, LWP which takes into consideration the depleted water from grass and livestock drinking would be birr 40.71/m3 (=birr18,859,700.85/463,318.05m3).

The calculation of LWP net of CWR of residues and grass is very important to compare WP of livestock, domestic use and crop in areas where the supply of water is fixed and an economic good. As a result, this analysis helps to show which activity is being generating the greatest benefit from the limited amount of harvested water in the study areas.

### 5.4- Domestic use of water productivity

Domestic water supplies are one of the fundamental requirements for human life. Without water, life cannot be sustained beyond a few days and lack of access to adequate and clean water supplies leads to the spread of disease. In addition to supporting the digestion of food, adsorption, transportation and use of nutrients and the elimination of toxins and wastes from the body (Kleiner, 1999), water is also essential for the preparation of foodstuffs and personal hygiene and sanitation.

In this section of the paper we try to share some issues concerning quantification of domestic use of water based on studies from other countries and following it domestic water productivity in the study areas will be presented separately.

***Some notes concerning quantification of water for domestic use***

The following literature is adopted from “Domestic Water Quantity, Service Level and Health” by Howard G. and J. Bartram (2003) to show some of the difficulties to quantify water used for home production.

To date, though, WHO has not provided guidance on the quantity of domestic water that is required to promote good health, some scholars tries to estimate the requirements for water for health-related purposes based on an acceptable minimum figure to meet the needs for consumption (hydration and food preparation) and basic hygiene. For instance, Howard and Bartram (2003), based on estimates of requirements of lactating women who engage in moderate physical activity in above-average temperatures, a minimum of 7.5 liters per capita per day will meet the requirements of most people under most conditions.

In their guidance manual prepared for the Department for International Development (UK), WELL (1998) suggested that a minimum criterion for water supply should be 20 liters per capita per day, whilst noting the importance of reducing distance and encouraging household connection. A similar figure has been suggested by other researchers (Carter *et al.*, 1997). Gleick (1996) suggested that the international community adopt a figure of 50 liters per capita per day as a basic water requirement for domestic water supply. This figure enables to meet most basic hygiene and consumption needs. Further more, frequent bathing, especially hand washing and laundering are also possible which result in positive health impact on both water-borne and water washed diseases.

White *et al.* (1972) also suggested that 2.6 liters of water per day is lost through respiratory loss, insensible perspiration, urination and defecation. In addition, a significant quantity of water is lost through sensible perspiration if hard work is performed. These figures led them to suggest that a daily minimum of water required in tropical climates would be around 3 liters per person, although the volume of water loss suggests that this should be at the upper end of this scale. They note, however, that under extreme conditions of hard work at high temperatures in the sun this figure could rise to as much as 25 liters per day. However, they also point out that the proportion of the fluid intake achieved via food would be expected to vary significantly and could provide 100% of the fluid requirement in some rare cases, notably pastoralists where milk was the primary food.

The reference fluid intake values for different reference body weights under different climatic and activity conditions are shown in table 5 below.

*Table 7: Daily fluid intake reference values in litres per capita (IPCS, 1994)*

| | Normal conditions | High average temp. 32°C | Moderate activity |
|---|---|---|---|
| Adults | 1.0-2.4, average 1.9 (including milk); 1.4 (excluding milk) | 2.8-3.4 | 3.7 |
| Adult male | 2 | - | - |
| Adult female | 1.4 | - | - |
| Child (10 years) | 1.0 | - | - |

*Source: Howard G. and J. Bartram (2003), Domestic Water Quantity, Service Level and Health, World Health Organization, Geneva, Switzerland.*

In developing countries, White *et al.* (1972) and Gleick (1996) suggest that a minimum of 3 liters per capita per day is required for adults in most situations. However, households with least access to water supplies are more likely to be engaged in at least moderate activity and often in above-average temperatures.

The discussion presented above indicates that the quantity of water required for hydration (whether via direct ingestion or food) should be a minimum of 2 liters for average adults in average conditions, rising to 4.5 liters per day under conditions typically facing the most vulnerable in tropical climates (see table 6 below) and higher in conditions of raised temperature and/or excessive physical activity. This figure can be interpreted as applying to all adults and to children, given the difficulty in determining whether the ration of adult/child water requirements would remain the same with increasing activity and/or temperature.

Table 8: Volumes of water required for hydration

| | **Volumes (litres/day)** | | |
|---|---|---|---|
| | **Average conditions** | **Manual labour in high temperatures** | **Total needs in pregnancy/lactation** |
| Female adults | 2.2 | 4.5 | 4.8 (pregnancy)<br>5.5 (lactation) |
| Male adults | 2.9 | 4.5 | - |
| Children | 1.0 | 4.5 | - |

*Source: Howard G. and J. Bartram (2003), Domestic Water Quantity, Service Level and Health, World Health Organization, Geneva, Switzerland.*

The basic need for water also includes water used for personal hygiene, but defining a minimum has limited significance as the volume of water used by households depends on accessibility as determined primarily by distance and time, but also including reliability and potentially cost. Accessibility can be categorized in terms of service level.

*Table 9 : Service level descriptors of water in relation to hygiene*

| Service level description | Distance/time measure | Likely quantities collected | Level of health concern |
|---|---|---|---|
| No access | More than 1000m or 30 minutes total collection time. | Very low (often less than 5 l/c/d). | Very high as hygiene not assured and consumption needs may be at risk. Quality difficult to assure; emphasis on effective use and water handling hygiene. |
| Basic access | Between 100 and 1000m (5 to 30 minutes total collection time). | Low. Average is unlikely to exceed 20 l/c/d; laundry and/or bathing may occur at water source with additional volumes of water. | Medium. Not all requirements may be met. Quality difficult to assure. |
| Intermediate access | On-plot, (e.g. single tap in house or yard). | Medium, likely to be around 50 l/c/d, higher volumes unlikely as energy/time requirements still significant. | Low. Most basic hygiene and consumption needs met. Bathing and laundry possible on-site, which may increase frequency of laundering. Issues of effective use still important. Quality more readily assured. |
| Optimal access | Water is piped into the home through multiple taps. | Varies significantly but likely above 100 l/c/d and may be up to 300l/c/d. | Very low. All uses can be met, quality readily assured.. |

*Source: Howard G. and J. Bartram (2003), Domestic Water Quantity, Service Level and Health, World Health Organization, Geneva, Switzerland.*

Where the basic access service level has not been achieved, hygiene cannot be assured and consumption requirements may be at risk. Therefore providing a basic level of access is the highest priority for the water and health sectors.

A minimum for basic health protection corresponds to 'basic access' and experience shows that this is equivalent to a water collection of less than 20 l/c/d, of which about 7.5 litres is required for consumption. The effective use in hygiene practices of the limited water available at basic access service level is important if available health benefits are to accrue. The basic level of supply should be regarded as a minimum quantity of water and attention paid to increasing levels of service to yard level in order to increase volumes of water collected.

Cairncross (1987) provides an example from Mozambique that demonstrated that water consumption in a village with a standpipe within 15 minutes was 12.30 litres per capita per day compared 3.24 litres per capita per day in a village where it took over five hours to collect a bucket of water. The excess water was primarily used for hygiene-related purposes. However, the difference in time points to the influence of only gross differences in service level, in this case between effectively no access and a service level that can be described as basic access.

*Table 10: Average water consumption figures, Jinja, Uganda (WELL, 1998)*

| Type of supply | Average consumption (l/c/d) | Service level |
|---|---|---|
| Traditional sources, springs or handpumps | 15.8 | Communal |
| Standpost | 15.5 | Communal |
| Yard tap | 50 | In compound |
| House connection | 155 | Within house (multiple) |

*Source: Howard G. and J. Bartram (2003), Domestic Water Quantity, Service Level and Health, World Health Organization, Geneva, Switzerland.*

Average consumption of water when it is piped into the home is relatively high (155 l/c/d), but decreases to 50 l/c/d when water is supplied to a yard level. When water is outside the home, average consumption drops still further to roughly one-third the average consumption at a yard tap and one-tenth that of households with water piped into the home.

Studies in Kenya, Tanzania and Uganda suggest that the quantities of water used for bathing (including hand washing) and washing of clothes and dishes is sensitive to service level (Thompson *et al.*, 2001). For houses using water sources outside the home, an average of 6.6 litres per capita are used for washing dishes and clothes and 7.3 litres per capita for bathing. By contrast for houses with a household connection to piped water supply use on average 16.3 litres per capita for washing dishes and clothes and 17.4 litres per capita for bathing. The authors suggest that for the households using a water source outside the home, the lesser volume collected has a negative impact on hygiene although this is not quantified.

With regard to cooking, defining the requirements for water for cooking is difficult, as this depends on the diet and the role of water in food preparation. However, most cultures have a staple foodstuff, which is usually some form of carbohydrate-rich vegetable or cereal. A minimum requirement for water supplies would therefore also include sufficient water to be able to prepare an adequate quantity of the staple food for the average family to provide nutritional benefit.

More water may be required to ensure that many of the foodstuffs can be cooked, although defining minimum quantities is difficult as this depends on the nature of the food being prepared. For instance, Gleick (1996) suggests that on average 10 litres per capita per day is required for food preparation, whilst Thompson *et al.* (2001) show that in East Africa only 4.2 litres per capita per day were used for both drinking and cooking for households with a piped connection and even less (3.8 litres per capita per day) for households without a connection. Taking into account drinking needs, this suggests that between 1.5 and 2 liters per capita per day is used for cooking.

If the quantity of water required for cooking rice (the available empirical evidence in India) is taken as representing the needs for staple preparation and assuming further water is required for preparation of other food, the evidence suggests that in most cases approximately 2 liters per capita per day should be available from domestic supplies to support food preparation. By adding the volume required for food preparation (2 liters) to the volumes identified in table 3, a figure for total consumption (i.e. drinking water plus water for foodstuffs preparation) of 7.5 liters per capita per day can be calculated as the basic minimum of water required, taking into account the needs of lactating women.

***Domestic use of water productivity (DWP)***

Discussion presented above can give some insights concerning the difficulties of quantifying the amount of water that must be available for various domestic purposes in many developing countries. Further more, valuing the outputs from domestic use of water is also another difficulty since most of these outputs are not bought and sold in the market especially in rural areas of Ethiopia. Similarly, it would be also difficult to set clear boundaries which output should be part of household production and which ones are part of crop or livestock productions in agriculture. Thus, in this study, domestic use of water is that amount of water that is used for drinking, cooking, bathing, washing clothes and utensils, food processing, house construction and production of handcrafts.

To measure the productivity of any input used in production, we calculate the value of total output per a unit of input used in that production process. Accordingly, the domestic water productivity (DWP) can be calculated using the formula

$$DWP = \frac{\text{the sum of all outputs produced using water as input}}{\text{quantity of water depleted in the production}}$$

To calculate DWP, the following information and assumptions are obtained from various sources.

a) According to the 1999/00 consumption and expenditure survey, annual expenditure for medication and health in rural Ethiopia is birr 105.72/hh (CSA, 2000).

b) Annual consumption expenditure on food in rural Ethiopia is birr 3422.04/hh (CSA, 2000).

c) Out of the total 57 hhs covered by SG-2000 survey, only 76% (or 43.32 hhs) have got positive change (see table 3) of availability of water for domestic use as a result of introduction of water harvesting technologies.

d) The WHO 20 liters/capita/day as a basic requirement of water for moderate health in poor developing countries is taken and distributed between drinking (3 liters), cooking (2 liters) and the rest 15 liters for hygiene and sanitation purposes.
e) The average family size of a hh in the survey areas is 7.95 ~ 8 (SG-2000, 2006) is also taken in the analysis.
f) The population data from 2004 welfare monitoring survey by CSA is taken to calculate the active labor force, i.e., age over 10 years (CSA, 2002) in the study areas, and hence, the active labor force is estimated to be 64% of the total population.

g) The author of this study understood from the discussion made between him and some of the staffs from Oromia Health Bureau, if a person got sick due to water related problems he/she may not go to work, with rough guess, for about 3 days in a year. This figure can increase or decrease depending on the accessibility of health stations. In addition to the patient, some of the family members may stay in home to take care of the patient. In the worst case if the patient dies from this disease, many people can lose some of their working days to attend the funeral service. Any way, for this study the lost man days due to sickness are taken to be 3 days/year. This method may help to approximate the lost labor in terms of Disability Adjusted Life Year (DALY).
h) Average wage rate for unskilled labor in Oromia region is birr 7.84/day (CSA, 2005) is taken as the minimum wage rate for rural labor in Oromia region.
i) The average price of local drink (i.e., *Tella*) is birr 0.83/liter (CSA, 2005).

*Table 11 - Water used for household (hh) production and its outputs*

| No | Water used for (1) | Number of beneficial household (hhs) (2) | Quantity of water used (lit/year/hh) (3) | Total quantity of water used by all hhs (m3/year) (4)=2x3 | Type of output produced (5) | Value of output from all hhs (Birr/year) (6) | Domestic WP (Birr/depleted water) (7)=(6)/(4) |
|---|---|---|---|---|---|---|---|
| 1 | Drinking | 43.32 | 8*3lit*366 | 380.523 | Improved health (better hygiene and sanitation) | 7,338.49 | 12.86 |
| 2 | Bathing | 43.32 | 8*15lit*366 | 190.261 | | | |
| 3 | Cloth washing | | | | | | |
| 4 | Washing utensils | | | | | | |
| 5 | Food processing (eg. crop washing, socking etc) | | | | | | |
| 6 | Cooking | 43.32 | 8*2lit*366 | 253.682 | Food stuffs | 168,997 | 666.18 |
| 7 | Brewing | 43.32 | 100 liters | 4.332 | Local drinks | 719.11 | 166 |
| 8 | Making mud plaster or bricks for constriction | 43.32 | - | 12.8 | Bricks | 2,560 | 200 |
| 9 | Producing handcrafts | 43.32 | - | - | Different handicraft products | 872.03[a] | - |
| | SUM | - | - | 841.598 | - | 179,614.6 | 213.42 |

[a] the value of handicraft products is not included in the sum.
*Source: own calculation.*

The numerator in the DWP ,i.e., the value of household productions (outputs) can be calculated as follows

*1) The value of improved health (column 6 in the table above)*

Health problems in rural Ethiopia are caused by different factors in which lack of water for various purposes is one of them. According to Oromia Health Bureau, 60-80% (average 70%) of the total health problems reported annually in Oromia are transmitted diseases, out of which about 65% are water related diseases. Then out of the total expenditure of birr 105.72 made by a hh annually, we may guess 70% can be devoted for transmitted diseases (70% *105.72) = birr74.004. And Again 65%*74.004 = birr 48.1026 is spent on water related health problems. We can say birr 48.1026/hh/year is the amount of money that would be saved as the result of the availability of water for personal hygiene and sanitation. Since the above mentioned health expenditure is representing the 2000 price, it must be changed to the current price. To change the 2000 price to the current 2006 price the inflation rate for medical care and health, i.e, 1.6% (CSA, 2006) is used. Therefore, the health expenditure that would be saved by each beneficial hh becomes birr 48.87 (=48.1026*1.6%) per year/hh. Since the total number of beneficial hhs are 43.32, the total health expenditure that would be saved by all hhs would be birr 2117.05/year.

In addition to the benefit indicated above, there is also a benefit from avoiding lost labor due to sickness which is related to the concept of Disability Adjusted Life Year (DALY). That means, if a person is getting sick due to water related diseases, he/she may stay for about 3 days in home without doing any work. So, if a person can get the minimum amount of water for basic hygiene and sanitation (i.e., 15l/c/d), the hh would save that amount of labor that would have otherwise been lost due to sickness. The value of the amount of labor that would have been lost due to sickness can be estimated as follows.

The active labor force (age over 10 years) in the study areas is 64% and the minimum wage in rural Oromia is birr 7.84/day (CSA, 2005). Given, the active labor force out of the total beneficial hhs is 222 (=43.32*8*64%), the minimum wage rate is 7.84/day, man days that would have been lost due to sickness of one person is 3 days/year, then the value of better health in terms of labor productivity gain is birr 5,221.44 (= 222*birr 7.84* 3 days).

The total value of improved health will, therefore, be birr 2117.05 + 5221.44 = birr 7,338.49.

*2) The value of food stuffs*

It is believed that much of the food stuffs consumed by a farming household are prepared/cooked using water as one of the inputs. Thus, the total value of food expenditure, i.e., birr 3,422.04 (CSA, 2000) made by a hh may be taken as a good proxy for the value of output from cooking. To change the 2000 price to the current 2006 price the inflation rate for food stuffs, i.e, 14% (CSA, 2006) is used. Therefore, the food expenditure becomes birr 3,901.13 (=3,422.04*14%) per year/hh. Since the total number of beneficial hhs are 43.32, the total food expenditure made by all these would be birr 168,997/year.

*3) The value of local drinks*

In Ethiopia in general and in rural areas in particular, there are many holy days and cultural and religious ceremonies that would be held in every year. So, to accomplish these events people produce local drinks such as Tella, Shamita, Borde, Buker/Karibo, Katikala and Teje. In the study areas there are Christian and Muslim hhs which can produce these local drinks for different occasions. Christian hhs may prepare such drinking like Tella, Katikala, Teje and Shamita. While Muslims prepare those drinks that are free from alcohol such as Buker/Karibo for holy days. In all cases water is used in larger quantity to produce these local drinks.

In this study, it is assumed that each hh may prepare one of these local drinks at least once in a year whether to celebrate one of the religious or cultural ceremonies and even for seal and in case of richer hhs they produce it for hh consumption at any time. Thus, if a typical hh may produce one water pot (= 1 Jerican = 20 liters) of Tella or Buker once in a year, the amount of water used by a hh for this purpose is estimated to be 5 Jerican or 100 liters. According to CSA (2005), the average price of Tella in Oromia region is 0.83/liter. Then, the value of local drinks produced by all beneficial hhs will be birr 719.11 (= 43.32hhs*20liter* birr 0.83/liter).

*4) The value of mud plaster or bricks*

Mud plaster or bricks are widely used for house construction in the study areas. In rural Ethiopia house constructions are, most of the time, associated with the number of marriages made in a village since newly married couples need to have their own residence house. Some people believe that the total amount of new marriages made every year in rural areas become decreasing due to the spread of poverty and small size of per capita land holding among farmers. Therefore young household members prefer to migrate to the urban center to look for jobs or they stay with their families till they accumulate some wealth which enable them to marry their partners. In other words, new house construction and marriages are frequently observed in relatively richer hhs in the study areas. For this study, “rich” hhs are defined as those hhs that own land above the average (2 ha/hh) land holding among hhs that are covered by the survey.

According to the SG-2000 survey data, those who own land more than the average land holding are only 25 (or 45%) and the rest 32 (or 55%) hhs own land less than the average. If we assume half or 50% of the “richer” and 10% of the “poorer” hhs are going to celebrate the marriage of one of their young hh members, then in the given year the total number of new houses that will be constructed for these newly engaged couples are estimated to be 16 (= 25*50% + 32*10%). The following assumptions are made in consultation with staffs from OIDA. A typical size of a house of a farmer is 4mx5m, height of the house is 2.5m, the size of the soil brick is 15cmx40cm, to produce one brick it may need 1 llitre of water, the price of a brick is birr 0.20. Then, to construct a house it needs 800 bricks or in terms of the cost of brick it would be birr 160 (= 800 bricks*birr 0.20). That means, if 16 houses are constructed annually, the cost of the bricks would be birr 2560 and totally 12800 liters or 12.8$m^3$ water would be used.

*5) The value of cottage/handicraft products*

In rural Ethiopia there are many types of handicraft products that are being produced by different small scale industrial activities such as weaving, pottery, masonry, carpet work, tailoring, wood/Bamboo work, leather tanning, manufacture of articles of straw & grass, and manufacture of leather (luggage, handbags, saddlery, harness, and footwear). The total number of establishments which produce the above mentioned articles in rural Ethiopia and rural Oromia are 616,696 and 190, 640 (30.91% out of the country total) respectively. The value added from these establishments (country total and Oromia region respectively) are Birr 267, 689, 000 and Birr 89, 315, 000 (CSA, 2003).

If we take the total number of households 4,436,738 in rural Oromia (CSA, 2004), then each hh in the study areas, on the average, may produce equivalent to birr 20.13/year of handicraft products. However, it is some what very difficult to estimate the amount of water that would be used to produce these products. The value of handicraft products from all beneficial hhs in the study areas may be estimated to be birr 872.03 (= 43.32* birr 20.13) per year.

Finally the sum of these five categories of values should give the value of the numerator of the DWP equation, though the fifth category (the value of handicrafts) are not included in the numerator due to the reason mentioned above. As indicated in the above table the sum of values of outputs produced from domestic use of water and the total quantity of water depleted in these production are Birr 179,614.6 and 841.598 respectively. Then, the DWP at GVO is

DWP = Birr 179,614.6/841.598 m3 = Birr 213.42/$m^3$ of water.

As we did in LWP, here also, the denominator of DWP can be expressed in terms of monetary terms. If we use the adjusted water tariff, i.e., 0.01538/lit, the value of the denominator of DWP will be birr 12,943.77. Then the DWP becomes birr 13.88/birr of water.

### 5.5- Crop water productivity

The total amount of water harvested in a given period of time is equivalent to the sum of water used for livestock, domestic use, crop production and some wastes which is not used in the present hydrological cycle. It is believed that in the study areas water is harvested, to the minimum, two times in a year: during spring (*Belge*) and the main rainy season (*kerimet*). Out of the total hhs covered by the survey there are about 33 hhs that harvest water using reservoirs with the capacity of 120 $m^3$ each and the rest 24 hhs use river diversion technology. In this study, only those hhs (they are 17) that harvest water from rain by reservoirs and at the same time they have complete necessary data for quantifying CWP are taken into consideration. However, due to presence of some negative outliers in the total values of output from irrigated plots (i.e., the numerator of the CWP equation), 7 hhs with birr of less than 250 of revenue from irrigated plots are rejected from the analysis. Finally, only 10 hhs are taken into consideration to obtain the magnitude of CWP in the study area.

The total amount of water harvested by these 10 hhs using their reservoirs is 2,520 m3/year which is used for livestock, domestic use and crop production.

Since each hh uses 53.17m3/year (22%) for livestock drinking, 19.43$m^3$/year (8%) for domestic use, then from the total harvested water in a year, the water used for vegetables and crop by these same 10 hhs would be 1,512 m3, assuming 252 $m^3$ (=10% of the total amount of water) is considered as waste due to siltation. In other words, of the total amount of water harvested each year only 60% is used for production of vegetables and other crops.

Even if we can not use the theoretical value of CWR as the denominator in the crop water productivity (CWP) equation due to lack of data, it is possible to estimate the CWP using the amount of water that is available for vegetables and crop production. This calculation of CWP has also an important relevance to assess the actual efficiency of water use in agriculture. Because the theoretical value of CWR shows only the minimum possible amount of water that could be used to produce the value of the numerator in the CWP equation but it is not the actual amount of water used in production. Thus, the CWP at GVO will be calculated using the usual formula but the denominator is not the magnitude of CWR rather the amount of water left in the reservoirs for vegetables and crop productions.

$$CWP = \frac{Total\ sales\ value\ of\ vegetables \,\&\, other\ crops\ grown\ on\ irrigated\ plots}{Amount\ of\ water\ availiable\ for\ irrigation}$$

The numerator of the CWP is the sum of sales values of vegetables & other crops (birr 10,465), earnings from green maize (birr 1,400) and fruits (birr 297).

*Table 12- revenues from sales of vegetables and other crops from irrigated land*

| Source of revenue | N | Minimum | Maximum | Sum | Mean | Std. Deviation |
|---|---|---|---|---|---|---|
| Total sales value of vegetables and other crops grown on irrigated plots | 10 | 270 | 2,275 | 10,465 | 1,046.50 | 715.92 |
| Sales from green maize (Bekolo eshet) | 1 | 1,400 | 1,400 | 1,400 | 1,400.00 | - |
| Total sales from irrigated fruit trees | 2 | 50 | 247 | 297 | 148.50 | 139.30 |
| quantity of water used for irrigation (m3) | 10 | 240 | 300 | 1,512 | 252.00 | 25.30 |

*Source: own calculation*

Then,

CWP = Birr 12,162/1,512 m3 = Birr 8.04/m3.

When the depleted water is valued at adjusted water price of birr 0.01538/lit, the CWP becomes birr 0.52/birr of water (=12,162/23,254.56). That means, to produce 0.52 birr value of vegetables and crops, one birr value of water was used. If we assume all the available water was used only for irrigation, we may think that there is a great deal of inefficiency in the use of water among these 10 hhs in the study areas. In other words, it would be better not to invest in this water or not to purchase it since by doing so we can save birr 0.48 for every one birr that would have been spent for irrigation. The principle of project feasibility study, i.e., the concept of opportunity cost becomes very important for deciding whether this magnitude of CWP is desirable or not. To have a feasible project, we have to earn more than what we have spent on a certain activity. Otherwise, the resource must be diverted to other ventures in which we can generate a better benefit.

Even though, the magnitude of CWP is found to be very low, these 10 hhs may be significantly benefited from water sales which in this study is not quantified any where. Since there is a practice of water selling in the study areas, all available water in the reservoirs may not be used only for irrigation purposes. If we would have known the amount of water that was sold in a year, this amount of water could have been deducted from the denominator in CWP and therefore the CWP would rise up. For the moment we take this problem as one of the limitations of the study in calculating the CWP.

### 5.6 – Comparison of water productivity magnitudes

The following table presents the summery of WP magnitudes of livestock, domestic use and crop productions.

Table 13 – comparison of LWP, DWP and CWP (Birr)

| Depleted water per year | LWP | DWP | CWP |
|---|---|---|---|
| CWR (residue+grass+drinking) (503,367.35 m3) | 37.47/m3 | - | - |
| Only Livestock drinking (3,030.76 m3) | 6,222.76/m3 | - | - |
| CWR (grass+drinking) (463,318.05 m3) | 40.71/m3 | - | - |
| Domestic use of water (841.598 m3) | - | 213.42/m3 | - |
| Water for vegetables & crops, not in terms of CWR (1,512 m3) | - | - | 8.04/m3 |
| Water at community price (birr 0.025/lit) | 1.63/birr of water* | 8.54/birr of water | 0.32/birr of water |
| Water at adjusted tariff( birr 0.01538/lit) | 2.65/birr of water* | 13.88/birr of water | 0.52/birr of water |

** values represent the monetary expression of 40.71/m3,i.e.,LWP from (grass+drinking).*
*Source: own calculation*

As indicated in table 12, the magnitude of DWP is found the greatest both in terms of the gain per m3 and per a unit of money (birr) of water. LWP found to be the next and CWP the least in rank. In other words, water devoted for domestic use generates the greatest benefit to hhs in the study areas. When we compare livestock and crop, obviously the benefit derived from livestock is usually superior than the crop. It is, most of the time, true in countries like Ethiopia where the mixed crop-livestock farming system serves as the major feed source for significant proportion of livestock in the country.

Though comparison of WP can best be done using the net value of output (NVO), the one presented in the above table- the gross value of output (GVO), can have some relevance to evaluate the efficiency of water use among rural households.

## VI- Conclusion and recommendations

### 6.1- Conclusion

The negative impacts of water scarcity on agricultural production and health become more pronounced in developing countries as these countries lack sufficient resources to adopt appropriate technology to mitigate these problems. Natural occurrences of hazards such as drought, desertification, and climate change and the influences of human activities like agriculture, population growth, deforestation, and land use changes are considered to constitute the major causes of the continuing deterioration of freshwater resources in these countries. Thus, given all these problems most people believe that the ever increasing demand for food must be met by increasing the productivity of water (and land) which are the most scarce resources in arid and semi-arid areas.

One of the technologies that help to conserve water for various purposes is rain water harvesting practices. Water harvesting in arid and semi-arid areas of Ethiopia is playing an important role in the effort to assure food security by expanding irrigation practices among farmers. Even tough, the way harvested water is used vary from household to household, in general, the water productivity from domestic use and livestock are found satisfactory and attractive for other people who have not yet adopted the technology. Regardless of lower CWP, farmers in the study areas have widely used irrigation for horticultural and other crop productions.

DWP stood first despite the importance of domestic use of water to the contribution of the overall output of the hh is usually overlooked by many people. Providing citizens with the minimum amount of water for drinking and hygiene has a spell over effect on all other activities in a hh. In areas where health problems are very serious, sufficient availability of water for hygiene and sanitation play an important role to get out of poverty. For instance, health experts in Ethiopia believe that it would be possible to reduce those diseases caused by inadequate & contaminated water, lack of sanitation and personal hygiene by 20%, 35% and 45% respectively if appropriate measures are taken against each of the causes. These figures imply that the significant proportion of health problems (about 65%) in Ethiopia are directly or indirectly associated with water borne and water washed diseases. Especially providing sufficient water for personal hygiene such as hand and face washing contributes a lot (45%) to reduce the occurrence of water washed diseases in rural Ethiopia. In all these cases it seems reasonable that the magnitude of DWP found to be the highest among the three sectors of agricultural productions.

Even if the WP magnitude of one sector is greater than the other, it would be very difficult to recommend a hh to use water for production of only one or two of the activities with the higher values of WP measure. Because all the three sectors (livestock, domestic use and crop) are complementary one to the other. Supplying sufficient quantity and quality of water to the hh maintains the health status of that hh which in turn enhances crop production which again improves LWP via supplying increased quantity of crop residues to livestock. Of course, when we consider the opportunity cost of family labor, we can recommend to use the harvested water only for one or two activities depending on the magnitude of WP measure. For instance, if the opportunity cost of labor is very low especially during the dry season, that labor can take those livestock to a distant place for watering (though it may result in lower production of livestock) then the fixed amount of harvested water may be used only for domestic use and vegetables/crop production. This higher production of crop supplies greater amount of feed to the livestock which may more than offset the loss in livestock production due to traveling those livestock a longer distance for watering.

Water harvesting technologies are also benefiting rural households by promoting vegetables feeding habit and change of working behavior. As water available for various purposes in the locality, labor would be fully employed as this water creates opportunity to work for much of the household members. As a result, it was observed that, family members would share work among them selves, planning their time, and get used to work on holidays. Water harvesting is also contributing positively to recharge ground water which considered as a positive environmental impact in rural Ethiopia.

### 6.2- Recommendations

Harvesting water in areas where there are no other sources of water for agricultural production is the only means available for farmers in Ethiopia. To use this harvested water efficiently it requires some policy intervention to minimize water wastage and to maximize the total values of all outputs produced from the given amount of water.

Though the main objective of introducing water harvesting technologies in the study areas is to secure food through irrigation practices, the importance of domestic use of water must not be underestimated in developing water projects. Thus, an integrated approach which enables to exercise systematic multi use water services (MUS) from a particular water scheme is believed to be one of the strategies to alleviate rural poverty. Providing farming households with sufficient water for drinking and personal hygiene/sanitation improves the health status of farmers which has a positive impact on household welfare and production. Availability of water in a homestead also imply increased time for child-care, food preparation, child schooling and productive activity. Thus, it is recommended that efforts must be put forth to create access to adequate water by those households which don't adopt water harvesting technologies so far.

As the LWP is found greater, farmers should be encouraged to practice livestock farming extensively through improving access to improved livestock species, veterinary services, credit facility and livestock marketing.

Since crop and livestock productions in Ethiopia are dependent one to the other, improving CWP also imply improving LWP. Therefore, it would be possible to increase irrigation efficiency through

- reducing water evaporation by using mulching, strip cropping and controlling weeds;
- introducing improved crop varieties whose water requirement is minimal;
- controlling deep percolation, seepage from canals, runoff return flows and canal excess water spills;
- improving non-water inputs in association with irrigation strategies that increase the yield per unit of water consumed;
- minimizing salinization;
- reallocating water from lower-value to higher-value crops;
- improving management of existing facilities(tankers, canals, pumps, etc);
- expansion of irrigated areas and increasing cropping intensity;

- adding water storage facilities-so that more water is available for release during drier periods. Storage can take many forms, including reservoir impoundments, groundwater aquifers, small tanks and ponds on farmers' fields.

One of the strategies to implement systematic and efficient MUS requires reusing of water that has already been used by other production activity. Reusing of water increases WP so that people must be aware how they avoid to pollute and treat polluted water when they reuse it.

When we talk to improve WP, the issue of product and input marketing must not be forgotten to design effective intervention in agriculture. Especially livestock marketing needs due consideration as livestock products such as meat and milk cannot be stored for longer time and transport longer distance because they are perishable goods. Thus, the development of marketing infrastructure (finance, transport, telecommunication, and so on) must be the integral part of agricultural development.

### 6.3- Further research directions

It is recalled that WP is the function of many economic, social, and agro ecological factors which can be whether endogenous or exogenous to the WP equation and to the farming household itself. Thus, to identify and analyze how these many of the factors affect WP, there must be available a detail primary quantitative panel data on household farming practices, adoption of agricultural technologies, health status & occurrences of diseases, consumption, income, and so forth. Data on the quantity of water used for various purposes and agro ecological factors about the study areas must also be collected as well. To this end, a comprehensive rural household survey must be conducted in a given area.

Having collected the above mentioned data, it would be possible to estimate econometrically the production frontier curve of an activity and hence possible to determine the level of efficiency of water use in that activity. By doing so, one can easily identify those factors which are responsible for lower/higher WP value and then can recommend the possible policy intervention on the basis of the sign and magnitudes of estimated coefficients.

## References

Asrat, M., Peden D., Molden, D.Taddesse, G.Haileselassie, A. and Gidyelew, T. (2006), Spread sheet Model to assess Livestock water productivity in the Nile River Basin, Ethiopia, (unpublished) International Livestock Research Institute, Addis Ababa, Ethiopia

Bakker, M., R. Barker, R. Meinzen-Dick, and F. Konradsen, eds. 1999. Multiple uses of water in irrigated areas: A case study from Sri Lanka. SWIM Paper 8. Colombo, Sri Lanka: International Water Management Institute.

Barbier B. E. (1998), The economics of environment and development, Selected essays, Reader, Environment Department, university of York, UK, Edward Elger Ltd.

Bekele S. and S.T Holden (2000), Policy instruments for sustainable land management: the case of highland smallholders in Ethiopia, Agricultural University of Norway, Department of Economics and Social Sciences, Norway

CSA(2001), Report on the 1999/00 household income, consumption and expenditure survey, statistical bulletin No. 258, A.A, Ethiopia.

CSA(2004), Statistical report on basic population characteristics, education, health, nutritional status and child care (Welfare monitoring survey), statistical bulletin No. 339-B, A.A, Ethiopia.

CSA(2006), Report on the 2005 national labor force survey, statistical bulletin No. 365, A.A, Ethiopia.

CSA (2003), Report on cottage/handicraft manufacturing industries survey, A.A, Eth

CSA (2005), Retail prices of goods and services (Annual average prices July 2004-June 2005), statistical bulletin NO. 345, A.A, Ethiopia.

CSA (2006), Consumer price index and its components (12 Months moving average), A.A, Ethiopia.

Daniel Kassahun (2005), Towards the development of differential land taxation system in Ethiopia, Environmental Researcher, Forum For Social Studies, Addis Ababa

Deng A. L. (2000), Integrating dry lands issues into country assistance strategies, The World Bank, Washington D.C. 20433, U.S.A.

Ethiopian Development Research Institute-EDRI (2005), Survey report on small-scale water harvesting structures, Addis Ababa.

Getachew Begashaw (2005), Community health, water supply and sanitation, Ministry of Health, Addis Ababa, Ethiopia

Girma Taddesse, D.Peden, D.Molden, A.Astatke, M.Asrat, W.Ayalneh and T.Gidyelew (2005), Livestock water productivity in the Nile river basin, ILRI&IWMI, Addis Ababa.

Herrero I. and S. Pascoe (2002), Estimation of technical efficiency: a review of some of the stochastic frontier and DEA software, Volume 15 issue 1, Economics network, Department of Economics, University of Portsmouth.

Howard G. and J. Bartram (2003), Domestic Water Quantity, Service Level and Health, World Health Organization, Geneva, Switzerland.

Kijne J. W., T.P.Tuong, J.Bennett, B.Bouman and T.Oweis (2000), Ensuring food security via improvement in crop water productivity, challenge program on water and food Background paper 1.

McCornick P.G., Kamara A.B. and Girma Tadesse. 2003. 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, 2-4 December 2002. IWMI (International Water Management Institute), Colombo, Sri Lanka, and ILRI (International Livestock Research Institute), Nairobi, Kenya.

Meselech Seyoum (2005), An overview of the Ethiopian Rainwater Harvesting Association (EHRA), Ethiopian Rainwater Harvesting Association (EHRA) Secretariat, Addis Ababa, Ethiopia

Ministry of Economic Development and Cooperation (1998), National economic parameters and conversion factors for Ethiopia, Addis Ababa, Ethiopia.

Molden D. and C. de Fraiture (2004), Investing in water for food, ecosystems and livelihoods, Blue paper Stockholm Discussion draft.

Molden D., H. Murray-Rust, R. Sakthivadivel and I. Makin (2003), A Water-productivity Framework for Understanding and Action, International Water Management Institute, Colombo, Sri Lanka.

Oromia Irrigation Development Authority-OIDA (2004), Evaluation report on benefits of water harvesting schemes implemented in 2003 (1995 E.C) in nine zones of Oromia region.

Peden D., Girma Tadesse and Mulugeta Mammo (2005), Improving the water productivity of livestock: An opportunity for poverity reduction, ILRI, Addis Ababa.

Peden D., A.Freeman, A.Astatke and A.Notenbaert (2005), Investment options for integrated water-livestock-crop production in sub-Saharan Africa, A contribution by ILRI: A report prepared by the IWMI for a collaborative program of NEPAD, African Development Bank, FAO, IFAD and the World Bank

Pender J., Lakew Desta, Menale Kassie, and Benin S. (2000), Land degradation and strategies for sustainable development in the Ethiopian highlands: Amhara Region Socio-economics and Policy Research Working Paper 32. ILRI (International Livestock Research Institute), Nairobi, Kenya.

Pereira L.S., I. Cordery and I. Iacovides (2002),Coping with water scarcity, IHP-VI Technical Documents in Hydrology No. 58 UNESCO, Paris

Perry C.J., M.Rock and D.Seckler (1997), Water as an economic good: A solution or a problem? in Kay M., T.Franks and L.Smith (editor), Water: Economics, Management and Demand, International commission on irrigation and drainage proceedings of the 18th European regional conference 'water-an economic good?' held in oxford, UK, Sep 1997.

Shih J.S, W. Harrington, W. A. Pizer, and K. Gillingham (2004), Economies of scale and technical efficiency in community water systems**,** Discussion Paper 04–15, Resources for the Future 1616 P Street, NW Washington, D.C. 20036.

Tesfay G., Berhanu Gebremedhin, and John Pender (2003), Community natural resource management: the case of woodlots in Northern Ethiopia, Environment and Development Economics, Cambridge University Press, United Kingdom

Yusuf K., Girma Taddesse, D.Peden and K.Sonder (2004), Irrigation water for livestock for better water productivity: A case study on small scale irrigation schemes

Zhang H. (19999), Improving Water Productivity through Deficit Irrigation: Examples from Syria, the North China Plain and Oregon, USA, *CSIRO Plant Industry, Wembley, Australia*

Annex 1- Parameters/assumptions used to quantify the amount of production from one unit of TLU (adopted from Asrat et.al., (2006)

**Milk production**

| | milkng days per year |
|---|---|
| Local cow 3 litres/day/cow) | 210 days |
| Improved cow (12 litres/day/cow) | 300 days |
| Goat (3.1 litres/day/goat) | 365.25 days |
| Camel (4.53 litres/day/camel) | 365.25 days |

**Meat production**

| | off-take rate(TLU) | carcass wt(kg) |
|---|---|---|
| cattle | 7% | (7%*250)* (110/250) |
| sheep | 34.50% | (34.5%*250)*(10/25) |
| goat | 34.50% | same as sheep |

**Hides and skin**

cattle off-take rate(kg)=off-take rate TLU*250/175=number of cattle slaughtered=no.of hides
sheep off-take rate(kg)/25=number of sheep slaughtered = no.of skins
goat off-take rate(kg)/25=number of goats slaughtered = no.of skins

**Animal power**

plowing
Total NO. of Local & improved Draft oxen/bulls*birr 10*180 days
24.5% of Total NO. of donkeys used for Draught*birr 10*180 days
9% of Total NO. of mules/horses used for Draught*birr 10*180 days

Trashing
Total NO. of Local & improved Draft oxen/bulls*birr 10*60 days

**Animal Transport**

Donkeys used for transport=70%of total no.of donkeys. benefit/year=70%of donkeys*birr 10*180days
Mules/horses used for transport=88%of total no.of mules/horses. benefit/year=88%of mules/horses*birr 10*180days

Manure production

| | Cattle (TLU) | Sheep (TLU) | Goat (TLU) | camels | Donkey (TLU) | Mules/horse (TLU) |
|---|---|---|---|---|---|---|
| Manure prod(000 ton/year) | 948.49 | 84.54 | 25.52 | - | 34.92 | 72.27 |
| Manure (000 ton/year/TLU) | 0.001150543 | 0.001369728 | 0.001369799 | - | 0.000876568 | 0.000876625 |
| Manure(ton/year/TLU) | 1.150543427 | 1.369727524 | 1.369799415 | - | 0.876567795 | 0.876624599 |
| Manure(kg/year/TLU) | 1150.543427 | 1369.727524 | 1369.799415 | - | 876.5677954 | 876.624599 |

**Prices**

- The average price of milk by woreda (SG-2000 survey)
  Addama birr 1/liter
  A/Negelle birr 2/liter
  Siraro birr 0.8/liter
  Alaba birr 2/liter
  Lume birr 1.18/liter

- Meat average price Oromia region is birr 15.73/kg (CSA, 2005)
- Hides birr 2/kg; average weight of one hide of cattle is estimated to be 40 kg
- Skin (sheep) birr 30/unit
- Skin (goat) birr 15/unit
- Animal power
  Animal (ox, donkey or mule/horse) rent Birr 10/day (ILRI, 2006)

- The average price of Dung cake in Oromia region birr 0.52/k.g (CSA, 2005) is taken to estimate the benefit from manure production in the study areas.