
GLOBALIZATION AND WATER RESOURCES MANAGEMENT: THE CHANGING VALUE OF WATER

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VALUING WATER FOR AGRICULTURE: APPLICATION TO THE ZAMBEZI BASIN COUNTRIES

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ABSTRACT: This paper aims to develop a method for assessing the economic value of water in agriculture under conditions of deficient data on crop production and water inputs, a typical situation in many developing countries. It is proposed to link the value-added approach for economic valuation to a model relating crop yields to water availability developed by U.N. Food and Agriculture Organization (FAO) specialists. The method proposed has been applied to assess the average and marginal values of water for several crops harvested in 1995 in the eight countries that share the Zambezi basin. Significant differences in the value of water were found for a same crop between countries, and between different crops within one country. Major variables that determine those differences are noted.

KEY TERMS: Water valuation; agriculture; Zambezi basin.

INTRODUCTION

The economic approach to decide about the most desirable allocation of water is to use the principles of economic efficiency to ensure that water is supplied to its most valuable uses. This is the reason why it is necessary to have theoretically sound estimates of the economic value of water in its different uses. Although herein we are considering only the use of water for agriculture, the same economic principles can be used within this sector to guarantee that water is efficiently allocated among the different crops, looking at each crop as one individual water user for that purpose.

There are a number of methods available to assess the economic value of water in agriculture: the method of integrating the demand function, the residual imputation method, the value-added method, and the alternative cost method. Each of them has its own context of applicability, which depends largely on the nature of the data available for performing the valuation exercise.

The context we deal with is particularly representative of developing countries. The hypothetical situation is that of having data on crop production much aggregated in space (national level) and time (annual basis), but not having data on production costs nor data on quantity of water used by or applied to the crops. To address such a situation in this paper a rather simple method is proposed, whereby a production model of the relationship between crop yields and water shortage is linked with a value-added approach for imputing economic value to the water evaporated and transpired by the crops.

The proposed method was applied to assess the economic value of evapotranspiration water for a number of crops in the eight countries that share the Zambezi basin, for the year 1995. In accordance with the aggregate nature of the available data, the results obtained are valid at a national level, for comparing the water values for the same crop between countries, and for different crops within one country.

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METHOD

We measure the economic contribution of water to agriculture according to a "value-added" concept. This contribution is assessed as the monetary value of agricultural (crop) production that is attained per unit of water used or consumed throughout the production process.

The situation considered is such that there are no available data on quantity of water used in agriculture production. Therefore, the first step of the method is a quantitative estimation of the water used by the crops. As there are available data on production per crop, the water use of each crop can be estimated.

Three measures can be used to describe the quantity of water use for agricultural production, namely: withdrawal, application and evapotranspiration. The three terms refer to different water flows and should not be used interchangeably.

Withdrawal refers to the total water diverted from surface water sources or extracted from ground water aquifers. *Application* refers to the water delivered to the field and excludes losses (and gains) during conveyance and delivery. Water applications are the portion of withdrawals that are directly under a producer's control. Irrigation management and use of improved irrigation technology can directly influence this quantity. *Evapotranspiration* refers to that portion of water withdrawn and applied that is actually consumed by evaporation, transpiration and plant growth. Evapotranspiration water is usually estimated based on plant water-requirement models. The amount of evapotranspiration is a better indicator of the water quantity lost to the immediate hydrologic cycle than the amount of total-water-use (withdrawal) (Hoekstra, 1998).

One assumption about the situation that we are dealing with is that there are no data available on water application nor on water actually used by the plants. The latter is a measure that can be readily assessed from physical models. Thus, evapotranspiration is the measure selected in our proposal to account for the quantity of water used by the crops.

Estimation of Evapotranspiration Water

To estimate evapotranspiration water, we used a method developed by FAO (Doorenbos & Kassam, 1979) to quantify yield response to water stress. This method gives account of the influence of water deficits on actual crop yields by expressing relative yield as a function of the ratio of actual to potential evapotranspiration.

Water deficits in crops, and the resulting water stress on the plant, reduce crop evapotranspiration and crop yield. Water stress in the plant is quantified by the ratio of actual evapotranspiration (E) to maximum evapotranspiration (E_{max}). If crop water requirements are fully met from available water supply then $E = E_{max}$. When water supply is insufficient, $E < E_{max}$. For most crops and climates E_{max} can be quantified.

The basic yield-evapotranspiration relationship is:

$$\frac{Y}{Y_{max}} = 1 - K_y \cdot \left(1 - \frac{E}{E_{max}} \right) \quad (1)$$

where Y is the actual harvested yield (ton/ha), Y_{max} is the maximum attainable yield (ton/ha), K_y is a yield response factor (non-dimensional), and E and E_{max} stand for actual evapotranspiration (mm) and maximum evapotranspiration (mm), respectively, during the growing period. Y_{max} and K_y are crop-related coefficients, which must be known. E_{max} is computed from the expression (Doorenbos & Pruitt, 1977):

$$E_{max} = K_c E_o \quad (2)$$

where K_c is a crop coefficient and E_o is what is called the "reference evapotranspiration", which depends on climate. K_c is tabulated for each crop. E_o can be computed from very simple to most sophisticated formulas (pan evaporation, Thornthwaite, Blanney-Criddle, Radiation, Penman-Monteith, etc.), or can be selected from general tables based on the climatic characteristics of the region. Under the given conditions of insufficient and aggregate data, the latter approach is the one followed for the application of this proposal to the Zambezi basin. The general crop coefficients are taken from literature sources (Doorenbos & Pruitt, 1977; Doorenbos & Kassam, 1979).

In its classical usage, the aim is to estimate the actual production Y , under the given condition of water supply. In the method that is being proposed here, the equation is worked out in the opposite direction to compute E , the

actual evapotranspiration, given the actual crop yield, which is an input data. Then, by algebraic manipulation of Equation (1), it follows that:

$$E = E_{\max} \cdot \left[1 - \frac{1}{K_y} \cdot \left(1 - \frac{Y}{Y_{\max}} \right) \right] \quad (3)$$

E , the depth of evapotranspiration water expressed in mm, can be further converted to volume of evapotranspiration water (W), in m^3/ha , by means of: $W=10 E$, where the factor 10 is used to get the referred units.

We made a modification with respect to the maximum obtainable yields used in Equation (3). It was observed that, with a few exceptions, the historical yields for the Zambezi countries were typically quite lower than the maximum values reported in literature, in some cases up to by several orders of magnitude. Only exceptionally the yields were higher than the standards of the literature, as it was the case for cotton in Botswana, for tobacco in Zimbabwe, and for wheat in Namibia, Zambia and Zimbabwe. Thus, by using the "literature" maximum yields, biased and in some cases inconsistent results are obtained. To overcome this inconsistency, it was decided to look at the time series on actual crop yields. Time series of 40-years length, from 1961 to 2000, were picked up from the FAOSTAT agricultural database (FAO, 2001). Then, the maximum observed value for each crop considered in each country was selected as the maximum yield Y_{\max} to be used in Equation (3). It is quite straightforward putting the historical maximum yield as the reference against which to compare the actual yields in order to infer the marginal values of the additional input (water) required for reaching those maximums.

Putting Economic Value to the Evapotranspiration Water

The economic value of evapotranspiration water, as computed here, is the physical productivity of water in terms of produced crop per unit volume of evapotranspiration water times the selling price of the crop. We use the value added approach to impute a value to this water. Each crop is considered as an individual economic sector in the value-added model. The expression to be used is:

$$B_{E_i} = \frac{V_i}{W_i} = \frac{Y_i \cdot P_i}{W_i} \quad (4)$$

where the subscript i stands for each crop considered, B_E is the average economic value or benefit of evapotranspiration water ($\$/m^3$), V is the value of crop production ($\$/ha$), Y is the actual yield (ton/ha), P is the crop selling price or producer price ($\$/ton$), and W is the volume of actual evapotranspiration water of the crop (m^3/ha). Similarly, the marginal benefit or value ($\$/m^3$) of evapotranspiration water for each crop i (MB_{E_i}) is given by:

$$MB_{E_i} = \frac{\Delta V_i}{\Delta W_i} = \frac{\Delta Y_i \cdot P_i}{\Delta W_i} \quad (5)$$

where ΔY is the marginal yield of the crop (ton/ha) and ΔW is the marginal volume of evapotranspiration water (m^3/ha). Equations (4) and (5) are applied to each selected crop in each of the countries considered.

APPLICATION TO THE ZAMBEZI BASIN COUNTRIES

Data

The data are gathered at national level on an annual basis. Eight countries share the Zambezi basin, namely: Angola, Botswana, Malawi, Mozambique, Namibia, Tanzania, Zambia and Zimbabwe. All of them are encompassed within the tropical region.

The estimation of the value of water for agriculture is performed on a per crop basis. The crops selected for the application are those for which available information exists on crop coefficients and yield-response factors, according to the model that was described above. Consequently, the following crops were considered: banana, bean

(dry), cabbage, citrus fruit, cotton (seed), grape, groundnut (in shell), maize, onion (dry), pineapple, potato, rice (paddy), sorghum, soybean, sugarcane, sunflower (seed), tobacco (leaves), tomato, and wheat. Not all these crops are sowed in all the countries every year. Besides, there are cases in which although a crop may have been sowed, full data on its production is not provided. Therefore, limitations on data preclude exhaustive analysis of the whole agriculture in the countries considered.

The basic source of data is the FAOSTAT agricultural database (FAO, 2001). The information is gathered and provided by FAO per country and per crop on an annual basis. This data encompass area harvested (ha), yield (ton/ha), and producer price, i.e. market selling price of the crop (local currency/ton). As a matter of convenience, 1995 was the year selected for analysis. Year 1995 is the most recent one for which data on producer prices (crop selling prices) and the older one for which currency exchange conversions are both available for all the Zambezi countries. In order to compare values between countries, the prices were converted to U.S. dollars (USD). The exchange rate as of 31 December 1995 is used as the reference point to perform the currency conversions. There are actual exchange rates available for all the eight Zambezi countries on that date and so comparisons are straightforward in this respect.

The following generic data are collected from the referred literature for each crop considered: K_c , non-dimensional crop coefficient; length of growing season in days; K_y , non-dimensional yield response factor; and Y_{max} , maximum (potential) yield, in ton/ha/growing season.

Results

A synthesis of the average evapotranspiration water values is presented in Table 1. Similarly, Table 2 presents the marginal values. These tables compare the average and marginal values for each crop between the countries that harvested that crop..

Table 1. Computed average values of evapotranspiration water (USD cents per m³)

	Angola	Botswana	Malawi	Mozambique	Namibia	Tanzania	Zambia	Zimbabwe
Bananas	1.0		2.5	1.4		3.2	0.3	0.8
Beans	1.1		1.8			4.9		1.8
Cabbages			26.5					
Citrus fruit	1.4	2.3	4.8	1.5		4.4	0.5	1.7
Grapes						13.4		3.8
Groundnuts	1.1	73.9	6.6	1.2		6.6	0.9	16.3
Maize	0.2	1.4	1.6	0.5	5.5	1.9	0.4	3.2
Onions			13.0			9.4	6.2	18.1
Pineapples	3.0			2.5		7.0		
Potatoes	8.1		46.1	8.4		16.1	3.2	32.1
Rice	0.6		3.7	0.9		3.3	0.3	5.7
Cotton	0.1		2.3				1.0	
Sorghum		8.4	1.5	0.7	1.6	1.7	0.2	1.5
Soybeans						0.9	1.1	11.0
Sugar cane	4.1		27.9	0.2		3.5	0.7	3.8
Sunflower	1.7	5.7	3.1	0.1		1.2	0.7	6.8
Tobacco	1.0		11.2			9.4	4.5	39.2
Tomatoes	3.9		21.7			37.9	3.9	9.5
Wheat	1.1	6.3	3.2	1.3	37.7	2.6	1.9	17.7

Table 2. Computed marginal values of evapotranspiration water (USD cents per m³)

	Angola	Botswana	Malawi	Mozambique	Namibia	Tanzania	Zambia	Zimbabwe
Bananas	1.3		3.3	1.9		4.7	0.3	1.0
Beans	1.4		2.0			5.7		2.2
Cabbages			24.7					
Citrus fruit	1.4	0.0	4.5	1.4		4.2	0.5	1.6
Grapes						10.9		3.2
Groundnuts	0.6	6.2	2.6	0.7		3.4	0.4	2.2
Maize	0.4	4.0	2.1	0.7	8.0	2.4	0.6	6.3
Onions			15.4			10.6	7.1	20.2
Pineapples	2.0			1.7		4.9		
Potatoes	0.0		55.7	9.3		17.8	3.6	35.4
Rice	0.8		4.8	1.3		4.3	0.4	7.4
Cotton	0.1		1.9				0.6	
Sorghum		4.2	1.2	0.5	1.2	1.4	0.2	1.0
Soybeans						0.8	0.7	6.7
Sugar cane	5.4		35.2	0.4		4.3	0.9	4.6
Sunflower	1.5	5.2	2.7	0.1		1.1	0.6	4.4
Tobacco	0.9		10.0			8.1	3.6	34.9
Tomatoes	4.1		23.0			39.8	4.1	10.0
Wheat	1.2	7.3	4.3	1.5	49.9	3.0	2.2	23.6

DISCUSSION

Table 1 allows making comparisons of the average evapotranspiration water values for each crop between the countries that harvested that specific crop. The differences between the countries are significant. Rising awareness on this fact could provide rational arguments to politicians and planners for fostering strategic agricultural alliances and international agreements to promote the improvement of social welfare via maximisation of the economic efficiency of agricultural water use within the Zambezi basin. For example, each country could be assigned to grow the crops that it grows most efficiently. Both the farmers and the nations' economies would profit from reallocations of water to higher valued crops.

On the other hand, looking at the differences in marginal values between crops within each country (Table 2), the national planners might argue that the principle of equimarginal value-in-use should be applied to attain economic efficiency in water allocation within each country. This principle states that marginal benefit per unit of water should be equal across all uses. As we are dealing with crop production only, we can consider each crop as an individual water user. The principle, then, is that the water should be allocated within each country such that all crops derive equal value in use from the marginal (the last) unit used or consumed. So, potential, beneficial agricultural water trade-offs could be fostered within each country.

The differences of water values are heavily dependent on variables such as the crop selling price and the water productivity. In some cases the price of the crop is the critical element explaining the value of the water input, whereas in other cases the water productivity has the larger weight. For example in Figure 1 it is shown that, according to our computations, Botswana and Malawi were found to have nearly the same water value for maize, which is largely explained in Botswana by the higher crop price whereas in Malawi by the higher water productivity.

A note must be introduced about the fact of using price as measure of marginal value in this study. To the extent that prices for agricultural goods are established under reasonably competitive market conditions, it is common practice to take the market determined price as the measure of the marginal value of such goods. Another note can be made with respect to the use of marginal value as an indicator of the economic value of a resource such as water. An alternative, and perhaps preferable, indicator of economic value would be the sum of consumer and producer surpluses. However, given the absence of data required for a reasonable credible estimation of consumer and producer surpluses, in this proposal we are opting for a measure based on what are presumed to be competitive prices. This approach is advocated and followed by Cummings *et al.* (1996).

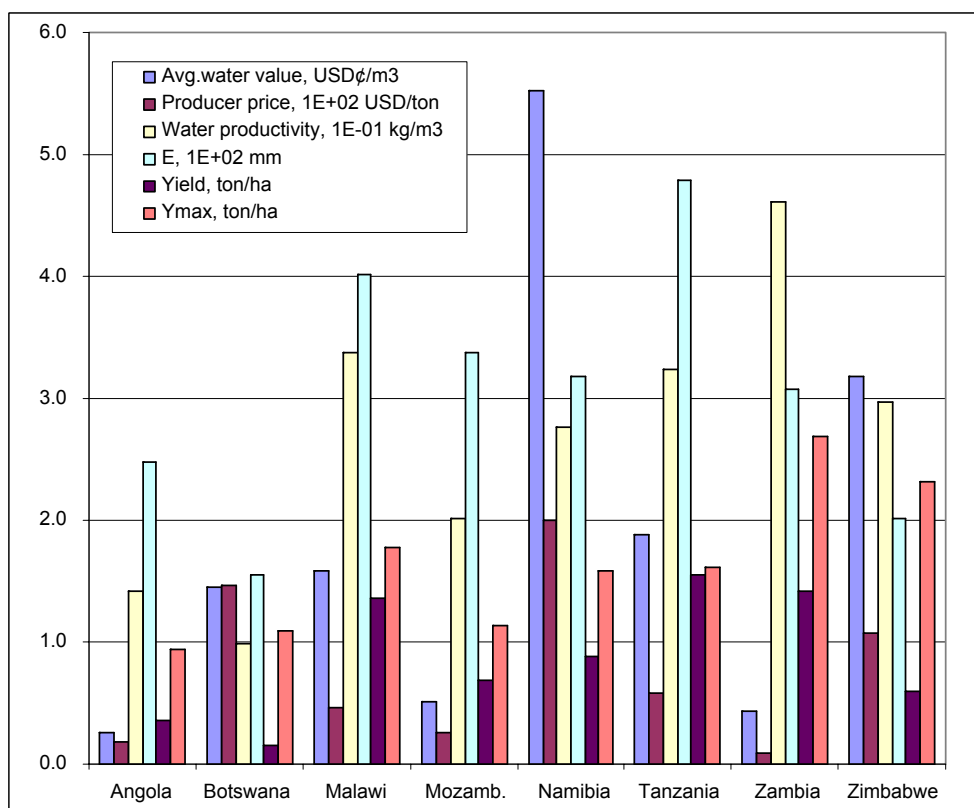


Figure 1. Variables in the determination of average evapotranspiration water value for maize

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