The value of rainfall: Upscaling economic benefits to the catchment scale

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Rainfall is priceless and is therefore often thought to have no value. This paper argues that nothing is less true and even introduces and applies a calculation scheme to *calculate* the value of rain. Knowing the value of rain is essential because rainfall is the principal source of water serving both ecosystems and human societies.

It is hypothesised that the value of a water particle in a certain place and at a certain point in time is the sum of its *direct* and its *indirect* value. The direct value of water is the value of the water *in situ*. The indirect value of water is dependent on its value in a later stage of its flow (downstream). The idea is that any value of water can be 'transferred' back to where the water came from. In other words, if a certain water particle gives some kind of economic benefit or supports some kind of ecological value in some spot at a certain moment, this water particle has a value not only at that point in space and time, but in its previous stages within the water cycle as well. The reasoning is that if the water was not there upstream it would not be downstream either, and thus there would be no economic benefit or ecological value. As a metaphor, one can say that water particles flow from upstream to downstream and that water values flow in exactly the opposite direction.

Following the above, the value of rain falls apart into two components: a direct and indirect component. The direct value of rainwater obviously relates to the value of water for plant growth. Where plant growth serves economic productivity (as in rain-fed agriculture), rainfall has a direct *economic* value. In other cases, where plant growth 'merely' serves to support the functioning of the ecological system, rainfall has a direct, but non-economic value. The indirect value of rainfall relates to the use and function of the rainwater once it entered the ground- or surface water system.

The paper elaborates the idea of water values flowing from downstream to upstream in a case study for the Zambezi basin. It is explicitly not the purpose of this paper to produce precise and validated estimates of all the different values of water in this river basin. We look at the value of water for a limited number of economic sectors and for these sectors we will give very crude estimates only. Thus we consider the value of water in the rain-fed and irrigated agricultural sector and in the domestic, livestock, industrial and hydropower sectors, but we do not look at ecological values of water (e.g. the value of water for the functioning of wetlands), option values or existence values.

Direct values of water

For the assessment of the direct economic value of water supplies in the domestic, irrigation, livestock and industrial sectors we used supply and demand curves for water. The marginal benefit of water generally decreases if the demanded quantity increases, because the willingness to pay for the first units of water is greater than the willingness to pay for the last units. The marginal cost of water supply as a rule grows with increasing supply, due to greater scarcity. The area between the demand and the supply curves represents the total economic value of water. The total net benefit of water is shared between 'producers' (the suppliers of the water) and 'consumers' (the users of the water). The distribution of the total net benefit over producers and consumers is determined by the price of the water, the amount of money paid by consumers to producers per unit of water. The consumer surplus is the area below the demand curve minus the price of water times the quantity consumed. The producer surplus is equal to the price of water times the quantity produced minus the area below the supply curve. The net benefit obtained is greatest if the marginal benefit equals the marginal cost.

In practice it often happens that the price of water is lower than the marginal costs, so that demand and supply are beyond the 'optimum'. In this case the consumer surplus is larger than in the optimum case, but the producer surplus is smaller. The net effect is negative (although there can be reasons to prefer this situation, for instance to provide poor people with subsidised water).

For the assessment of the value of rainwater in both rain-fed and irrigated agriculture and for the assessment of the value of river runoff for hydropower we had to use a more indirect method.

Rainwater does not have a price, nor do farmers incur costs in order to make the rain available, so that it is difficult to obtain demand and supply curves for rainwater. Nevertheless, water is an important input factor in the crop production process and should therefore be valued. The demand for rain can be seen as a 'derived' demand, which means that it depends on the demand for crops. The value of rainwater is in fact a derivative of the value of the crops produced. We have estimated the value of rainwater in rain-fed agriculture as follows. We started by drawing a *crop* demand curve. This demand curve was then used to assess the gross benefit of crop production. The total costs of crop production were estimated by assuming them to be a fixed percentage (85%) of the gross product of rain-fed agriculture. This gross product – which can be understood as the gross income of farmers – was calculated using the SGVP-method. The standardised gross value of production (SGVP) is defined as:

$$SGVP = \sum_{crop=1}^{crop=i}\left(A_i \times Y_i \times \frac{P_i}{P_b}\right) \times P_{world} \tag{1}$$

where A_i represents the area planted with crop i (in ha), Y_i the yield of crop i (in kg/ha), P_i the local price of crop i (in local currency/kg), P_b the local price of a reference crop (in local currency/kg) and P_{world} the world market price of the reference crop (in USD/kg). As a reference crop we have chosen maize. The demand for 'maize equivalents' (in kg/yr) is calculated as the SGVP (in USD/yr) divided by the world market price for maize (in USD/kg). This demand for 'maize equivalents' together with the price of maize gives one point of the crop demand curve. The curve is further defined by assuming a certain price elasticity of crop demand and a certain maximum willingness to pay. The net benefit in rain-fed agriculture is equal to the area below the crop demand curve (the gross benefit) minus the total costs of crop production (assumed to be 85% of the SGVP). This net benefit is a measure of the value of the resources used in the production process. Water is one of these resources (input factors), as are – for instance – land, fertiliser, capital and labour. If we suppose that water is the limiting factor, a reduction in water will result in reduced crop production and thus a reduced benefit. In the most extreme case, if there was no rainwater at all, crop production would be zero. For this reason, we have assumed that the total value of rainwater falling on rain-fed croplands is equal to the net benefit in the rain-fed agriculture sector. For the sake of simplicity we have presumed that the total production of crops responds linearly to the amount of possible water uptake by plants.

To estimate the value of rainwater in *irrigated* agriculture we simply assume that the rainwater uptake by plants in the irrigation sector has the same value per unit of water as in the case of rain-fed agriculture.

The assessment of the value of river runoff in the hydropower sector has been approached in the same way as rain-fed agriculture. We have used a demand curve for energy to estimate the gross benefit from hydroelectric power. The gross product in the hydropower sector is calculated as the total energy production (in GJ/yr) times the energy price (in USD/GJ). It has been assumed that the costs of hydropower production amount to 80% of the gross product.

The flow of water values from downstream to upstream

To estimate how a direct value of water at some point in the water cycle gives indirect values to the water upstream of this point, we can simply follow the water back along its flow lines. If we do so, we will see that all water originates in precipitation. Accordingly, if we systematically transfer values of water in the upstream direction, we will find that the total value of precipitation in a river basin is equal to the sum of all *in situ* values of water in the basin. This makes sense: the total value of precipitation exactly equals the benefits it will generate on its way to the ocean or back into the atmosphere.

When a set of water flows leaving a water store produces a certain value, this value must be attributed to the inflows into the water store in proportion to their volume. Applying this general rule, we can calculate the total economic value of a specific water inflow as follows:

$$TV_{in,i} = DV_{in,i} + \frac{Q_{in,i}}{\sum_{j=1}^{n} Q_{out,j}} \times \sum_{j=1}^{n} TV_{out,j} \tag{2}$$

The first component ($DV_{in,i}$) is the direct value of inflow i and the second component refers to the indirect value of this flow. $TV_{out,j}$ refers to the total value of outflow j, $Q_{out,j}$ to the volume of outflow j and $Q_{in,i}$ to the volume of inflow i.

Zambezi case study

Based on the calculation methods described, we have formulated a 'water-value model' for the Zambezi basin and linked this to a hydrological model of the basin. The water-value model calculates the direct values of water per sector and sub-basin and describes how these *in situ* values add value to the water flows upstream of where the *in situ* values are generated.

The total economic value of water in the Zambezi basin has been calculated at 2.3×10^9 USD in the year 1990. It was found that agriculture provides the largest contribution to this total. Irrigated and rain-fed agriculture each contribute a little more than 30%. Domestic water use contributes about 22%, industrial water use 9%, livestock water use 4% and hydropower 3%. The profits from the use of water are not equally divided among producers and consumers. In all sectors, the consumer surplus is larger by far than the producer surplus.

In the case of the irrigation sector the producer surplus is even estimated to be negative, as a result of under-pricing of the water. The farmers in this sector survive due to water subsidies from the government. In rain-fed agriculture the producer surplus is relatively large, which can be understood from the fact that rainwater is not paid for.

The total economic value of water in the Zambezi basin is not equally divided over the various sub-basins. About 30% of the total value is generated in the Lake Malawi-Shire basin, 26% in the Lower Zambezi basin, 17% in the Middle Zambezi basin, 10% in the Kafue basin and 7% in the Luangwa basin. The remaining 10% is generated in the three basins furtherst upstream. The general picture which appears is that water in the Zambezi basin has the highest direct value in the downstream parts. In the Upper Zambezi, Barotse and Cuando-Chobe basins water provides relatively low direct economic benefits. However, because these basins are situated in the upstream part of the Zambezi basin, water here has the highest *indirect* value. In the Upper Zambezi basin for instance, only one third of the total economic value of precipitation is due to the benefits of the water in the basin itself. The remaining two thirds of this total value derives from use of the water in downstream parts of the Zambezi basin.

The value of river runoff

Let us start with considering the economic value of the Zambezi water at its downstream end, where it flows into the Indian Ocean. In the current analysis we have assumed that there is no economic activity in the marine waters which will be affected significantly if the Zambezi outflow into the ocean becomes zero, so the value of the river runoff into the ocean is regarded as zero. If we follow the river in the upstream direction, however, the value of the river water will not remain zero.

River runoff from the Middle Zambezi basin for instance has an estimated total economic value of 150×10^6 USD/yr, due to the use of water in the Lower Zambezi basin (Fig. 1). The total values of river runoff from the Kafue, Luangwa and Lake Malawi-Shire basins are lower, because these basins make a smaller contribution to the total river inflow into the Lower Zambezi basin. However, the value per cubic metre of river runoff is the same for the Middle Zambezi, Kafue, Luangwa and Lake Malawi-Shire basins. This can be understood from the fact that the total value of the river inflows into the Lower Zambezi basin has been equally divided among the four upstream basins which contribute to this total river inflow. If we go further upstream we see that the value per cubic metre of river flow increases.

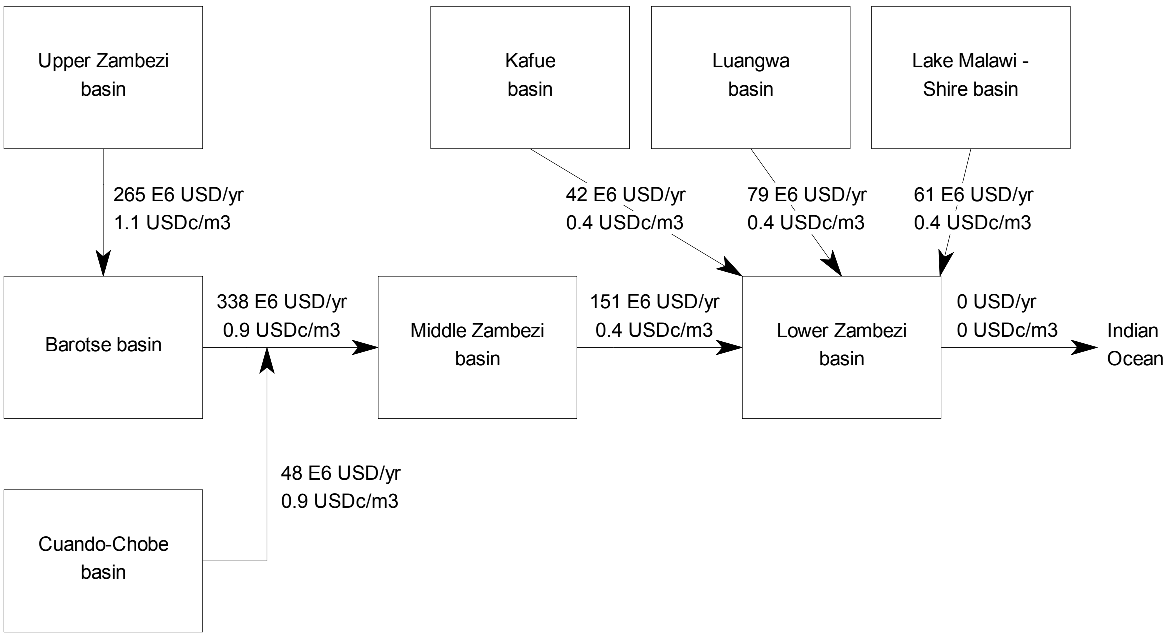

Fig.1. The total value and average value per unit of river runoff per sub-basin in 1990.

The *marginal* value (i.e. the value of the last unit) of water in a river is generally less than the *average* value per unit of water. As an illustration we have analysed the marginal value of the river runoff from the Barotse basin and considered the plan to export 3×10^9 m^3/yr from the Zambezi river at Katima Mulilo (Namibia) to South Africa. This volume of export will reduce the mean annual river runoff from the Barotse basin by about 8%. Without export, the value of the river runoff from the Barotse basin is estimated at 340×10^6 USD/yr. Export reduces this value by about 5%. From these data one can calculate a marginal value of river runoff of 0.5 dollar cents per cubic metre, which can be regarded as the opportunity cost of exporting water to South Africa. It should be noted that this is a conservative estimate, because not all types of water value have been considered. Additionally, demands for water in the Zambezi basin are likely to increase in the future, so that water will become scarcer and thus more valuable. The analysis shows that the opportunity costs of water export from the basin become lower if one moves the location of withdrawal in a more downstream direction.

The value of rainwater

The total value of precipitation in the Zambezi basin is 2.3×10^{9} USD/yr, which is equal to the total economic value of water in the different sectors. With an average rainfall of 875 mm/yr we can then calculate an average value of rainfall in the Zambezi basin of 0.2 dollar cents per cubic metre. This does not mean that the value of precipitation is the same throughout the basin. The average value of rainfall in the Lake Malawi-Shire basin for instance is 0.6 dollar cents per cubic metre. The average value of rainfall over rain-fed croplands in the Zambezi basin is calculated at 1.1 dollar cents per cubic metre. The latter value largely reflects the value of rainwater to rain-fed agriculture, but it also includes a small component referring to the use of the water in later stages of the water cycle.

Model experiments with more or less rainfall show that the *marginal* value of rainfall is much higher than the average value per unit. An increase in precipitation of 1% for instance gives an increase in the total economic value of 12%. A decrease in precipitation of 1% gives a decrease in the total value of 7%. This means that the marginal value is about 1.8 dollar cents per cubic metre. This high value is due in particular to the high marginal value of precipitation in rain-fed agriculture. Reduced precipitation will directly result in reduced yields and this translates into reduced benefits for both consumers and producers. The second sector contributing to the high marginal value of precipitation is hydropower, which depends directly on the available river flows and thus indirectly on precipitation. In the case of the other sectors reduced precipitation has a much more indirect effect. Water supply costs will increase as a consequence of growing water scarcity, thus resulting in reduced benefits, but this mechanism will become significant only if precipitation is reduced by a much higher percentage than just 1%.

Discussion

The study shows that the value-flow concept offers the possibility of accounting for the cyclic nature of water when estimating its value. As such, we think that the concept deserves further elaboration. We have touched upon several possible uses of the methodology. One can address for instance questions such as: what is the value of rainwater, how does the value of river water increase if we move from downstream to upstream, what is the value of a return flow, and what are the opportunity costs if we withdraw water from a location? One could also use the method to assess how spatial planning can have different effects on the net benefits of water or how climate change might affect the benefits of water. Equally, the methodology can be used to put the issues of water scarcity (valuable water) and flooding (non-valuable water) in one context. Downstream use of water increases the value of the upstream water. But the presence of downstream risks as a result of flooding puts a negative value on the upstream water.