Economic Efficiency of Water Storage Options: An Application of the Approach to Ghana

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Abstract

Water storage is widely promoted as an effective method for mitigating some of the adverse impacts of climate change. Cost benefit analyses is one approach to evaluate which is the most appropriate water storage type under any specific biophysical and socio-economic conditions. However, such methods often result in loss of significant information for those characteristics which cannot be easily assessed using monetary values. Against this background, the study reported in this paper developed an outranking methodology, designed with threshold systems and weighting values, in order to overcome some of the constraints of traditional cost-benefit analysis. The method has been applied in three representative catchments in central and northern Ghana.

Keywords: Water storage, climate change, outranking approach, thresholds, Ghana

1. Introduction

Procedures for water storage selection often resort to a form of cost-benefit analysis (CBA) to identify the most appropriate option. However, in cases where imperfect market conditions exist and non-market goods and services occur, CBA may lead to non-optimal results.

The first weakness of CBA arises from the strong comparability principle, which stems from the monetization of heterogeneous goods and services (Hanley and Spash, 1998). The monetization of all elements inevitably leads to reductionism and loss of information about the nature of each factor (Munda, 1996). Second, the assumption of the absolute substitutability among goods and services also causes errors, since in reality this is not always the case (Munda, 1996). For instance, the revenues derived from the electricity sold by a hydro-electricity plant will often outweigh the financial costs arising from the displacement of communities and the flooding of ancient forests. Consequently, the option identified through CBA as the best option, should not necessarily go ahead.

Another major constraint arises from the potential irreversibility of conditions associated with the development of water storage. For example, the construction of a hydropower dam often entails in soil erosion due to clear-felling, siltation of downstream areas and loss of wildlife (Mishan, 1981). The issue of ecosystem complexity is another major issue that is poorly handled by the CBA method. For example, the climate change projections for Sub-Saharan countries indicate the likelihood of increased rainfall variability in many places (IPCC, 2007). If these climate change scenarios occur it may drastically affect the costs and benefits over the lifetime of a planned water storage project.

Institutional capture is another major impediment to CBA, mainly represented by inter-generational inequities. The notion of a discount rate is often used to address trade-offs between generations. In many instances, this is a highly arbitrary process associated with the identification of a discount rate which is used to attribute values to environmental goods and services which will be inherited by future generations (Söderbaum, 2005). In relation to distributional aspects and intra-generational issues, this is often a highly contested approach which is aligned with the core concept of economic theory. The principles of economic theory are based on the identification of the most efficient utility level on an individual basis without considering the distributional and equity aspects of the efficiency (Munda, 1996).

To overcome the aforementioned constraints, we propose a method that is based on a multi-criteria outranking approach (Roy, 1996). The suggested method assesses diverse indicators related to both economic performance and environmental impacts of water storage schemes. The approach also attempts to enumerate the gains and losses between different users. The suggested approach has been tested by evaluating the performance of different small reservoirs and the effects to upstream and downstream users in three catchments in central and northern Ghana.

2. The Outranking based approach

Our concept is based on the principles of decision aiding approaches. These can be divided into two types, “descriptive” and “constructive” Vincke (1994). A descriptive approach focuses on the identification of pre-existent preferences. This assumes that for whoever’s preference is sought, they are predefined and pre-exist in a stable state. The descriptive approach forms the basis of the development of a simple and comparable System of Preference Relations (SPR), which is based on the strict preference and indifference conditions (Roy, 1996). In the descriptive approach, the most efficient solution should be identified using trade-off processes between different criteria. The descriptive approach delineates the concept of optimization usually through a single criterion. The CBA method is a representative descriptive approach where the monetization of all results should identify the best solution.

However, over the last two decades, the difficulty of adequately comparing and quantifying heterogeneous criteria, such as the environmental and economic ones in water resource projects, has steadily increased (Munda et al, 1994). As a result, the “constructive” approach has been developed. In this approach, apart from the “strict preference” and “indifference” conditions, the “weak preference” condition is introduced. In the “weak preference” situation, two possibilities could prevail in which one criterion is weakly preferred to another or vice versa. Table 1 below summarises each of the three preference conditions.

Table 1. Preference conditions through a constructive approach (Vincke 1994, adjusted by authors)

Conditions	**Definition**
Strict Preference	Corresponds to the existence of clear and positive reasons that justify significant preference in favor of one (identified of the two actions).
Weak preference	Corresponds to the existence of clear and positive reasons that invalidate strict preference in favor of one (identified) of the two actions. The reasons are insufficient to deduce either strict preference in favor of the other action or indifference between the two actions, thereby not allowing either of the two preceding situations to be distinguished as appropriate.
Indifference	Corresponds to the existence of clear and positive reasons that justify equivalence between any two actions.

By adopting the above set of conditions, the proposed methodology attempts to establish an outranking based approach that avoids the inherent constraints of traditional CBA. The operationalisation of an outranking-based approach based on the constructive concept demands the introduction of specific relations and values. To help clarify the basic concepts, the essential components of the outranking approach are given below:

a, b = Alternatives of a proposed project (e.g. a= big reservoir, b= small reservoir)
j = A number of j criteria proposed for the ranking of the examined alternatives
p = strong preference threshold , q= indifference threshold

Initiating from the "strict preference" condition, a threshold value (p) establishes that a strict preference occurs only when the difference between the examined alternatives is beyond the defined value. In mathematical form, and assuming a maximization criterion without loss of generality, this condition is expressed as below:

a**P**b (a is strongly preferred to b) ⇔, $g(a)-g(b) > p$ (1)

Next, the "weak preference" condition is represented by the introduction of another threshold value (q) which is added to the strict preference above. The condition is then presented through a double threshold model, where a binary relation measures weak preference as below:

a**Q**b (a is weakly preferred to b) ⇔ $q < g(a)- g(b) < p$ (2)

In effect, the thresholds q and p comprise the lowest and highest values that could ever occur between the two alternatives. The weak preference should be determined within the range of these two values. Finally, there is also the indifference condition where the preference of one alternative (a) over another (b) is lower than the weak preference threshold and hence is considered as nominal. The model of this condition is expressed as:

a**I**b (a is indifferent to b; and b to a) ⇔ $g(a) - g(b) < q$ (3)

The relations of strict, weak preference and indifference situations are operationalized as follows:

$$c_j(a,b) = \begin{cases} 1 & g_j(a) + q_j \geq g_j(b) \\ 0 & g_j(a) + p_j \leq g_j(b) \\ \theta & q_j \leq g_j(b) - g_j(a) \leq p_j \qquad \theta = \dfrac{p_j + g_j(a) - g_j(b)}{p_j - q_j} \end{cases} \tag{4}$$

Where $g_j(a)$, $g_j(b)$ = the performances of alternative scenarios *a* and *b* respectively for each criterion *j* , p_j, q_j = the preference and indifference thresholds respectively.

The values of 0, 1 and θ presented in equation (4), decipher the following messages:

a) 1 = when the difference between the two alternatives *a* and *b* for jth criterion is smaller than the indifference threshold; b) 0 = when the difference between the two alternatives *a* and *b* for jth criterion exceed the preference threshold; c) θ= when the difference between the two alternatives *a* and *b* for jth criterion is between the indifference and preference thresholds

Through the operationalisation of the preference conditions, an outranking relationship (S) between any two alternatives a and b can be constructed. The outranking relation can be interpreted as ‘’a is at least as good as b (aSb)’’ or "a is not worse than b". It should be mentioned that these relationships are applied to each of the j criteria; that is, a**S**jb means that "a is at least as good as b with respect to the jth criterion" (Fülöp, 2008).

Many of the outranking-based approaches handle the distributional and significance related concerns by introducing multipliers, commonly known as weighting factors (DTLR, 2002). To this end, we introduced higher co-efficient to those criteria which better reflect the linkage of water storage with livelihood status. The weighting assumptions are necessarily subjective and require that the analysts should wisely judge the significance of the criteria in order to avoid bias in the assessment process. However, weight factors are currently the most widely applied approach for the consideration of distributional aspects (Seager, 2004).

We then calculate the findings of the outranking approach. Customarily, in most of the outranking based approaches (Roy, 1991), a formula composed by the weighting factors is applied. Usually a fraction is designed with nominator as the multiplication of weights and outranking results, and with the denominator representing the sum of the weights:

$$C(a,b) = \frac{1}{w}\sum_{j=1}^{n} w_j C_j(a,b) \qquad (5)$$

Where a,b = water storage options, w = weigthing factor, C_j = the outranking processes among the options and the criteria

3. Application of the approach to Ghana

The economic performance of water storage in Ghana is defined by a set of diversified indicators divided into two different groups. These indicators are effectively input criteria in the outranking approach presented above. In the first group, the criteria are related to the direct and indirect economic effects of water storage to agricultural (cultivation and livestock) and domestic water use. The second group relate to the level of satisfaction of farmers about water use in agriculture and domestic sectors (Table 2).

Table 2. Criteria of economic performance for water

Group 1 : Direct and Indirect economic effects	
Net revenues from agricultural produce	Ratio of net revenues from agricultural produce and water charges
Impact of Water Use on Health	Water for Domestic Use
Ratio of net revenues from agricultural produce and water consumption	
Group 2 : Farmers’ preferences in water use	
Level of satisfaction from water volume in crops	Level of satisfaction from water volume in livestock
Level of satisfaction from water quality in crops	Level of satisfaction from water quality in livestock
Level of satisfaction from water abstraction methods in crops	Level of satisfaction from water abstraction methods in livestock
Level of satisfaction from water volume in domestic sector	Level of satisfaction from water quality in domestic sector
Level of satisfaction from water abstraction methods in domestic sector	

The two groups of criteria are combined in order to determine the most effective economic performance of a water storage scheme.

The testing of the methodology was conducted in 3 small reservoirs in the Volta Basin of Ghana, namely; Sata in Ashanti Region, Vea in Upper East Region and Golinga in Northern Region

(Figure 1). The objective of the analysis was to assess the economic performance of water storage types in downstream and upstream users through the aforementioned criteria. For the Sata case there was no “downstream” so only households in the upstream were interviewed. In the cases of Vea and Gollinga, the users of existing small reservoirs were surveyed. In total, five 3 upstream (Gollinga, Vea and Sata) and 2 downstream (Gollinga and Vea) options were examined. For each site, 200 households were interviewed; 100 from households living upstream and another 100 living downstream. In all, 500 households were surveyed.

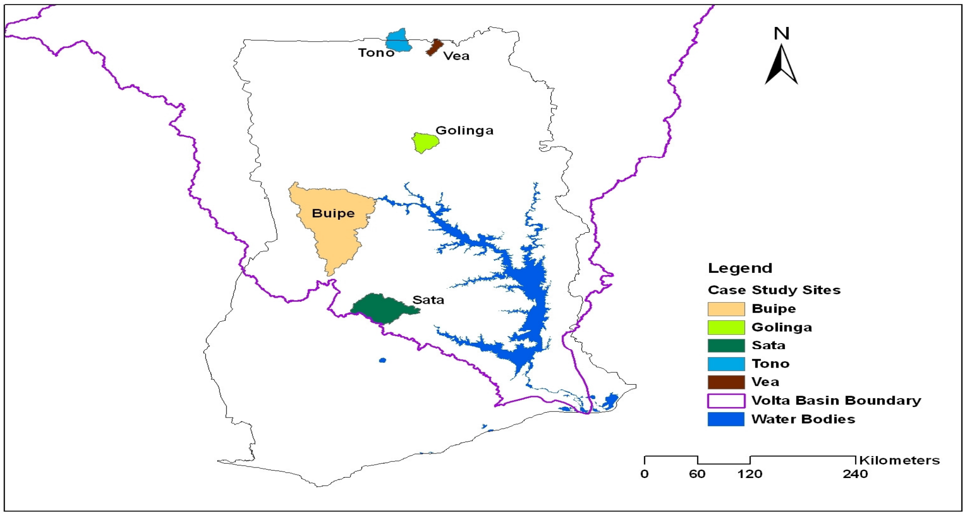

Figure 1. Case studies East and North Ghana

For the application of the outranking approach, a set of preference and indifference thresholds were introduced while the weighting factors were also inserted. The calculation of the thresholds and weights was conducted according to the relevant guidelines suggesting the relation between the thresholds and co-efficient (Vincke, 1994).

Table 3. Thresholds and values

Criteria	Net Rev.	Rat. Net Rev./Wtr	Imp. Wtr Hlth	Wat.Dom.	Rat. Net Rev./Con.	Pref. Cr.
Indif. Thrs	100	100	30	5	6	1
Pref. Thrs	150	150	60	10	12	2
Wgt.	1.2	1.3	1.1	1	1	1

Note: Net Rev. = Net revenues from agricultural produce, Rat. Net Rev./Wtr=Ratio of net revenues from agricultural produce and water charges, Imp. Wtr Hlth. = Impact of Water Use on Health , Wat. Dom.= Water for Domestic Use, Rat. Net Rev./Con=Ratio of net revenues from agricultural produce and water consumption, Pref. Cr. =Preference related criteria, Indif. Thrs.= Indifference thresholds(q), ,Pref. Thrs.= Preference threshold (p), Wgt= Weights

The performances of the five alternative options in Vea, Gollinga and Sata were ranked for each criterion in a pair-wise manner through equation (4) (e.g Vea Upstream Vs. Gollinga downstream, for the criterion “Impact of Water Use on Health”). The aggregated performance of all criteria for each pair-wise outranking was then assessed through equation (5). Finally, all the performances of the pair-wise outranking combinations among the options attributed a final scoring index as below (Table 4):

Table 4. Outranking assessment

Options	**Vea Upstream**	**Vea-downstream**	**Gollinga-upstream**	**Gollinga-downstream**	**Sata-upstream**
Vea- Upstream	-	0.454545	0.606	0.606	0.606

Vea-downstream	0.303	-	0.606	0.757	0.606
Gollinga-upsteam	0.303	0.303	-	0.454	0.454
Gollinga-downstream	0.303	0	0.564	-	0.606
Sata- upstream	0.151	0	0.454	0.454	-
Total	**1.06**	**0.75**	**2.23**	**2.27**	**2.27**

As displayed in table 4, the upstream area of Sata together with downstream of Gollinga present a better performance among the other water storage options. Little behind stands the upstream area of Gollinga whereas both the Vea areas perform significantly worse than the other options.

4. Conclusions

This study attempted to provide a methodology for the identification of efficient water storage options in regard to climate change effects by also capturing the trade-offs between upstream and downstream farmers. The application has overcome the simplifications occurring through the application of a cost-benefit analysis by aligning with the economic theory through the adoption of mainstream economic criteria. The additional introduction of environmental and technical related criteria attempted to capture the information related with water storage options. These diversified set of criteria was assessed though a systems of thresholds and weighting factors for the avoidance of complete trade-off assumptions which entails in knowledge reductionism and high uncertainty in the final outcome. It is considered that the suggested approach should be better applied through the introduction of more diversified criteria and also more heterogeneous storage options. However, the current results could offer an insight on the performance and effects of different water storage options through a solid and transparent approach.

References

Clawson and Knetsch, J.L., 1966. *Economics of Outdoor Recreation*. Baltimore, Maryland: John Hopkins Press.

IPCC 2007. *Climate Change, 2007.* Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), Cambridge University Press, Cambridge, UK

Department of Transport, Local Government and Regions (DTLR) 2002, *Economic Valuation with Stated Preference Techniques*, Edward Elgar, Cheltenham, UK.

Fülöp, J., 2008. *Introduction to Decision Making Methods,* Laboratory of Operations Research and Decision Systems, Computer and Automation Institute, Hungarian Academy of Sciences

Hanley N. and Spash C., 1998. *Cost Benefit Analysis and the Environment*, Edwar Elgar Publ, 275pp

Mishan E.J., 1981. Introduction to Normative Economics, Publ. Oxford University Press

Munda, G., 1996. Cost-benefit analysis in integrated assessment: some methodological issues, *Ecological Economics* 19, pp. 157-168

Roy, B., 1991, The outranking approach and the foundation of Electre Methods, *Theory and Decision* 31: 49-73, 1991.

Roy, B., 1996. *Multicriteria Methodology for Decision Aiding.* Kluwer Academic Publisher, Dordrecth.

Seager, T., P. 2004, Understanding industrial ecology and the multiple dimensions of sustainability. *In Strategic Environmental Management by O'Brien and Gere Engineers*. New York: John Wiley & Sons

Söderbaum, P. 2005. Democracy, decision-making, and sustainable development: dam-construction as an example, *Int. J. Water, Vol. 3, No. 2, 2005* 107

Vincke, P., 1994. *Multi Criteria Decision Aid Methods.* Kluwer Publ., The Netherlands.