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ASSESSING THE PERFORMANCE OF IRRIGATION SCHEMES WITH MINIMUM DATA ON WATER DELIVERIES[1]

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ABSTRACT

This paper highlights an approach to assessing the performance of the water delivery system from the perspective of farmers. The methodology uses the concept of fuzzy set theory to analyse the responses from farmers concerning their perception of the irrigation service provided. The paper takes the view that as part of performance assessment of schemes where data on water delivery are not available or their integrity cannot be guaranteed, it is possible to use farmers' assessment to determine how effective the water delivery system is. The methodology was applied in a case study of Dawhenya irrigation scheme in Ghana. By decomposing the utility into reliability, timing and tractability and subsequently applying fuzzy set theory to the analysis of the linguistic responses of farmers, this study has enabled us to assess how well the water delivery system is performing from the point of view of the most important stakeholders – the farmers. The analysis indicated that the most important factor was reliability followed by tractability and timing in that order, while the farmers' level of satisfaction with the factors in order of increasing satisfaction was: timing, reliability and tractability. Copyright © 2001 John Wiley & Sons, Ltd.

KEY WORDS: irrigation systems; performance; assessment; minimum data

RÉSUMÉ

Ce document s'intéresse à une manière d'évaluer la performance d'un réseau de distribution d'eau du point de vue des fermiers. La méthode utilise le concept de la théorie de fuzzy set pour analyser les réponses des fermiers concernant leur perception des services d'irrigation fournis. Le document part du principe que pour l'évaluation de la performance des réseaux pour lesquels les données concernant la distribution de l'eau ne sont pas disponibles ou leur validité ne peut être garantie, il est possible d'utiliser l'avis des fermiers pour déterminer l'efficacité du réseau de distribution. La méthode a été appliquée dans le cadre de l'étude du réseau d'irrigation de Dawhenya au Ghana. En décomposant les critères de jugement en fiabilité, temps et accessibilité et en appliquant ensuite la théorie de fuzzy set à l'analyse des réponses qualitatives des fermiers, cette étude nous a permis de contrôler l'efficacité du réseau de distribution de l'eau du point de vue des intéressés les plus importants: les fermiers. L'analyse indique que le facteur le plus important est la fiabilité suivi de l'accessibilité et le temps dans cet ordre, alors que pour les

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fermiers l'ordre est: le temps, la fiabilité et l'accessibilité.

MOTS CLÉS: réseaux d'irrigation; performance; contrôle; données minimum

INTRODUCTION

Conventional methods of assessing water delivery performance all depend on flow measurements. Indeed, adequacy and equity which have become the standard criteria for assessment of the water delivery system can only be evaluated when flow data at various levels and points of the irrigation system are available and reliable.

However, in most irrigation schemes in developing countries, the reality is that flow measurement is not accorded a high priority (Rao, 1993; Lankford, 1998; Horst, 1999). If data on flows are available at all, their quality may not be guaranteed (Murray-Rust and Snellen, 1993). This is particularly true at lower levels of the irrigation system. The reasons for the general lack of data on water deliveries are many, but the most important are equipment malfunction, lack of desired equipment and lack of motivation on the part of staff to collect such data.

The important question then is "Can the performance of schemes be assessed to some extent without reference to data on water delivery?" This paper highlights one approach to an alternative assessment methodology, which bypasses the need for quantitative data on water delivery. It concentrates on the water delivery system since criteria for the other subsystems are fairly straightforward and, importantly, they do not rely much on water delivery data. The methodology uses the concept of fuzzy set theory to analyse the responses from farmers concerning their perception of the irrigation service provided. The paper takes the view that as part of performance assessment of schemes where data on water delivery are not available or their integrity cannot be guaranteed, it is possible to use farmers' assessment to determine how effective the water delivery system is.

A METHODOLOGY BASED ON FARMERS' ASSESSMENT OF THE UTILITY OF WATER SUPPLY

It is important to realise that there are several stakeholders in the business of irrigation – donors, farmers, government officials, project workers, etc. Among this set of interested parties, the least attention has been paid to performance viewed from the perspectives of the most fundamental stakeholders – the farmers. It is the farmers who are the consumers of the irrigation services provided by the system and the producers of the agricultural outputs. Notable exceptions, which explicitly suggest a set of criteria for evaluation from a farmer's point of view, are Chambers (1988) and Svendsen and Small (1990).

IRRIGATION AS A SERVICE

Before describing the methodology used in the assessment, it is important to consider the issue of irrigation as a service to be provided for farmers. This concept of service has often been overlooked in favour of large-scale inputs (gross water supply, total acreage, etc.) and gross output indicators of success or failure (internal rate of return, cropping intensity, etc.). The internal indicators, which measure and evaluate the processes between initial and final output are not audited, analysed or discussed in appraisal reports. The concept of providing service in irrigation projects is relatively new, although it has been promoted before (Merriam, 1973). The idea of assessing performance including some measures of service is even more recent.

The water delivery service at any layer in the distribution system was defined by Burt (1997) to include:

1. Specification of the water right of the beneficiary (for example, cubic metres per hectare per season for volumetric deliveries or proportional allocation of available supplies in the case of uncertain supplies);
2. Specification of the point of delivery (farm level, user association, 'chak' outlet);
3. Flexibility in rate of delivery (fixed, variable, variable between limits);
4. Flexibility in duration (fixed, variable but predetermined, variable by agreement); and
5. Flexibility in frequency (every day, once per week, undefined).

The first point above relates to the determination of adequacy and equity of the supply. For most upland crops the estimation of adequacy and equity necessarily requires data on water delivery. However, for basin rice the problem of scarce water delivery data may have limited implications for adequacy and equity determination. This is because the supply may be considered adequate or not depending on the presence of a water depth or a lack of it in the basin. The level of equity too can be estimated from a similar reasoning.

The last three ingredients of service mentioned above can usefully be discussed under three characteristics of the supply, which measure the utility of the water supply schedule to the farmer (Svendsen and Small, 1990). These are:

- Tractability, which refers to the ability of the farmer to satisfactorily apply water of a given stream size to the land. Very small stream sizes may lead to uneven application of water, with large percolation losses in portions of the fields close to the turnout. Very large stream sizes, on the other hand, may lead to soil erosion, destruction of bunds, crop damage, and excessive amounts of water running into drains.
- Convenience, which refers to the time of arrival of water at the farmer's outlet. Farmers often have preferred times during the day to irrigate. These preferences generally involve irrigation during daylight hours, though farmers in the Gezira Scheme in Sudan have been reported to prefer irrigating at night to avoid extreme daytime temperatures in the fields and to lower labour costs. They are also likely to prefer to avoid having to irrigate on festival days.
- Predictability, which refers to knowledge of future supplies planned by the water supply organisation and the degree of uncertainty associated with this knowledge. Predictability is important to farmers in three ways. First, by knowing when and in what quantities water will arrive, a farmer can better plan the timing of his activities and avoid wasting time travelling back and forth between his home and his fields. Second, by reducing the uncertainty facing the farmer as he makes management decisions concerning the amount and timing of the use of inputs complementary to water, predictability can improve water use decisions. A farmer who faces a great deal of uncertainty about the supply of irrigation water may irrigate when water is available, even if the crop is not in great need of additional water. One likely outcome of such a situation is over-irrigation that may lead to waterlogging. Although predictability does not necessarily eliminate the problem (since the water may predictably arrive at inappropriate times) it is likely to reduce it.

It must be noted that the different requirements of basin rice, as compared to upland crops, necessitate a somewhat different decomposition of the utility. In this case, *predictability* becomes *reliability* and relates to the farmer's degree of confidence that the basin will remain flooded. *Convenience* in terms of the time of arrival at the farmer's outlet has little meaning in the context of continuous flow basin irrigation. In this case the *timing* of presaturation and planting (i.e. start of the season) is more important. *Tractability* refers to the delivery flow rate and in this case relates particularly to control over initial land preparation and avoidance of subsequent inundation.

To measure any of these requires data on flows at farm level which, as has been already discussed, are usually not routinely available. Direct measurement is therefore not a feasible approach. Also, the assessment can realistically only be provided by the farmer.

AN APPROACH BASED ON FUZZY SET THEORY

An approach based on fuzzy set theory will be used to assess farmers' satisfaction with the quality of the irrigation service provided them. It is based on a *quantitative* evaluation of farmers' judgements. In this method, the farmer uses *qualitative* expressions rather than ratings to judge the appropriateness of each of the three factors of utility of water supply (reliability, timing and tractability) and their importance to the farmer under the farmer's individual circumstances in the field. Fuzzy set mathematics (Zadeh, 1965) can then be used with these judgements to measure the overall utility of the water supply schedule to that farmer and to aggregate the opinions of a number of farmers. The motivation for using fuzzy set theory is that it provides a systematic approach for representing and processing farmers' assessments of the quality of irrigation service.

Fuzzy sets – definitions and concepts

In the context of evaluating the convenience of the supply schedule, let A be the set of "supplies with low flow rate". In classical set theory, the response from any farmer will either be a member of this set or not. The farmer's degree of membership is therefore either 1 or 0. However, if A is a fuzzy set, then partial membership is possible. For any member X_i in a fuzzy set A, the degree of membership (written $\mu(X_i)$ and called the support of X_i in A) is a real number between zero and one (inclusive) which indicates a degree of belief that the element X_i is a member of the fuzzy set A. A support of $\mu(X_i) = 1$ means that X_i is clearly a member of the set A and a support of $\mu(X_i) = 0$ means that clearly it is not. In the example of the set of "supplies with low flow rate", if the range of possible flow rates is denoted by $U = (X_1, X_2, \ldots, X_5)$, where X_1 and X_5 are the lowest and highest possible flow rates respectively, then set A can be represented as:

$$A = \{X_i|\mu(X_i)\} = \{X_1|\mu(X_1), X_2|\mu(X_2), \ldots, X_5|\mu(X_5)\} \quad (1)$$

The term $X_i|\mu(X_i)$ is called the support function and in this case is represented by the expression

$$A = \{1|1, 2|0.5, 3|0.1, 4|0, 5|0\} \quad (2)$$

This indicates a steeply declining degree of belief that larger flow rates (i.e. 3, 4 and 5) belong in the set of supplies with low flow rate. The choice of the shape of the support function is subjective, but final analysis is not sensitive to small variations (Ayyub and Haldar, 1984; El-Awad, 1991).

The farmer utility (FU) which measures the overall utility to the irrigators follows a procedure described by Schmucker (1984) for the calculation of the fuzzy weighted mean. If N_i is the set of M integers and W_i is the set of their weights, then the arithmetic weighted mean N of these integers is given by

$$N = \frac{\sum_{1}^{M} N_i * W_i}{\sum_{1}^{M} W_i} \tag{3}$$

If the elements of both N_i and W_i are fuzzy sets then the farmer utility, FU, is calculated, using Equation (3) and Table I, as

$$\mathrm{FU} = \frac{(\mathrm{GOOD} * \mathrm{VERY\ HIGH}) + (\mathrm{MEDIUM} * \mathrm{LOW}) + (\mathrm{BAD} * \mathrm{VERY\ LOW})}{(\mathrm{VERY\ HIGH} + \mathrm{VERY\ LOW} + \mathrm{LOW})} \tag{4}$$

Each fuzzy element in Equation (3) has support functions as shown in Table II, which are used to perform the calculations. The numerator will give a fuzzy set with 75 elements and the denominator with 15 elements. The computations using the support functions and a universe of five elements as in Table II have been programmed by El-Awad (1991). The output is presented in the form of a linguistic expression describing the overall utility of the water supply schedule to the farmer. The linguistic expression is then converted into a numerical scale.

The application of some operation on two or more fuzzy sets will not, in general, result in a support function which exactly corresponds to one of the linguistic expressions as summarised in Table II. Methods are available (such as the best-fit method) to translate a derived fuzzy set to its nearest natural language expression. For example if one farmer provides the assessment given in Table I, then the derived fuzzy set corresponding to his overall assessment will be (from Equation (3)):

Table I. Hypothetical farmer assessment

Factor	Judgement	Importance
Reliability	Good	Very high
Timing	Medium	Low
Tractability	Bad	Very low

Table II. Selected fuzzy expressions and their support functions

Linguistic expressions	$\mu(1)$	$\mu(2)$	$\mu(3)$	$\mu(4)$	$\mu(5)$
Very good/Very high	0	0	0.01	0.25	1
Good/High	0	0	0.1	0.5	1
More or less good/More or less high	0	0	0.4	1	0.4
Medium	0	0.4	1	0.4	0
More or less bad/More or less low	0.4	1	0.4	0	0
Bad/Low	1	0.5	0.1	0	0
Very bad/Very low	1	0.25	0.01	0	0

$$\text{FU} = \{1|0.46, 2|1.0, 3|0.65, 4|0.37, 5|0.31\} \quad (5)$$

Clearly this does not correspond exactly with any of the support functions given in Table II, but the nearest expression obtained by the best-fit method is "more or less bad".

Aggregating farmers' opinions

Farmers' opinions on each of the three factors can be aggregated. A first step in this regard is to give an indication of the diversity of opinions on the factors. Znotinas and Hipel (1979) defined divergent aggregation (DVG) as a measure of the range of opinions thus:

$$\text{DVG} = (F1 \cup F2 \cup F3 \cup F4 \cup F5) - (F1 \cap F2 \cap F3 \cap F4 \cap F5) \quad (6)$$

where $\cup$ and $\cap$ denote the union and intersection of the sets $F1 \ldots F5$.

To convert this measure of diversity of opinions into a numerical index, a diversity index (DI) has been defined as the average of the supports of the DVG. Clearly, from the definition of DVG, the larger the difference of opinions between the farmers the higher the support of the DVG and, therefore, their average. In general, a high diversity index indicates differences in opinions of the farmers on the factor under consideration (or its importance). A low diversity index, on the other hand, indicates their agreement, but it is not necessarily a sign of satisfactory water supply schedule. The index takes its minimum value of zero when all farmers have identical opinions and its maximum value of unity with the maximum possible disagreement.

The aggregation of different viewpoints expressed in the form of fuzzy statements can be obtained by several methods. According to Nguyen (1985), the best method is to calculate the average support given by the farmers to each element in the set, add it to the maximum support and divide by two. The resulting support function can then be normalised and/or made convex if required. It can then be approximated to the nearest linguistic expression by using the best-fit method with each of the linguistic expressions of Table II.

Application to Dawhenya smallholder irrigation scheme

To demonstrate the relevance of fuzzy set theory, the methodology is applied to the Dawhenya smallholder irrigation scheme, which is located on the southern border of the Dangbe West District of the Greater Accra Region of Ghana. The scheme has a potential cultivable area of 450 ha, but at present utilises only about 200 ha for rice cultivation. At present, there are about 240 tenant farmers with an average holding of 1 ha.

Physical construction of this pumped and gravity-fed irrigation project was started in 1961 and completed in 1975. It was rehabilitated in 1992. After rehabilitation, the project developed plans to involve farmers in its management with the view to eventually turning over management to them. By 1996, most of the management activities had been transferred to a farmers' Co-operative Union. At the moment, the Co-operative Union has engaged the services of a full-time business manager who is responsible for the overall day-to-day activities of the scheme. The Irrigation Development Authority, which is the government agency in charge of irrigation development, maintains a skeletal staff for maintenance and extension services. At Dawhenya, even though there are a number of flow measurement devices located on the canal network, most of these are not in good working condition. Adequate flow monitoring will not only require replacement or repair of this equipment but also training of staff regarding its use.

Selection and interview of farmers

A stratified sample of 30 farmers was selected from a list that contains the names of farmers according to their location on the laterals. This was done to ensure that the 'top/bottom' effect could be investigated. A preliminary survey was conducted with the group to find out about their perception of performance assessment and the problems associated with their activities. This informal discussion enabled the farmers to talk about their concerns and problems related to the irrigation supply. Their perspectives on performance assessment as they relate to the irrigation supply were then incorporated in the formulation of the questionnaire.

The farmers were then interviewed on an individual basis on their plots. They were asked questions concerning the three main factors of the supply utility – reliability, timing and tractability. They provided answers to the appropriateness of each of the factors and their importance to them under their individual circumstances in the form of linguistic expressions. These expressions ranged from "very good"/"very high" to "very bad"/"very low". Fuzzy set mathematics was then used with these judgements to measure the overall utility of the water supply schedule to the farmer and to aggregate their opinions.

RESULTS AND DISCUSSIONS

In all, 30 farmers were interviewed. The analysis indicated that the overall utility for the farmers ranged from medium to high with the majority being more or less high (i.e. more or less satisfied).

Table III indicates that for the farmers interviewed, the most important factor was reliability followed by both timing and tractability. Using the utility values, it is quite clear that tractability was the second most important factor, with timing being the least important. This is quite interesting, and might be explained by the fact that at Dawhenya, timing is determined by the management and the weather conditions (particularly rainfall) in any season. The farmers thus have no choice but to "conform" to the start-of-season arrangements. Using the utility values again, their level of satisfaction with the factors in order of increasing satisfaction is: timing, reliability and tractability.

For farmers who cultivated Bouake, those at the "top" end of the lateral recorded the highest utility (0.70–0.80) (Table IV). This was followed by the "middle" farmers (0.65–0.77) and then the "bottom" farmers (0.64–0.74). There was a similar trend for farmers cultivating the variety Tox. While these results are not surprising for irrigation schemes, the significant thing to note is that the farmers interviewed are generally satisfied with the irrigation supply since the utility is at least 0.59 in all cases.

The scatter diagram (Figure 1) which depicts the relationship between utility and yield according to the location of the farmers indicates that the "top" farmers with generally high

Table III. Aggregation and divergence of opinions on individual factors and their importance

Factor	Description			Importance		
	Term	Utility	DI	Term	Utility	DI
Reliability	More or less good	0.61	0.88	High	0.75	0.63
Timing	More or less good	0.60	0.86	More or less high	0.55	1.0
Tractability	More or less good	0.75	0.63	More or less high	0.72	0.63

Table IV. Utility according to location (Bouake)

Location	Utility
Top	0.70–0.80
Middle	0.65–0.77
Bottom	0.64–0.74

utilities produced high yields followed by the "middle" and "bottom" farmers in that order. Again, when the effect of utility on yield is assessed by computing the average yield and utility when the farmers are grouped according to their location along the laterals, an interesting relationship emerges. As Table V shows, the "top" farmers (with the highest average utility) had the highest average yield followed by the "middle" and "bottom" farmers in that order. These results confirm the view that in most irrigation schemes, farmers at the top end of laterals usually have an advantage in terms of water allocation over their colleagues further down the laterals. This situation, in most cases, results in better yields for such farmers. It must be pointed

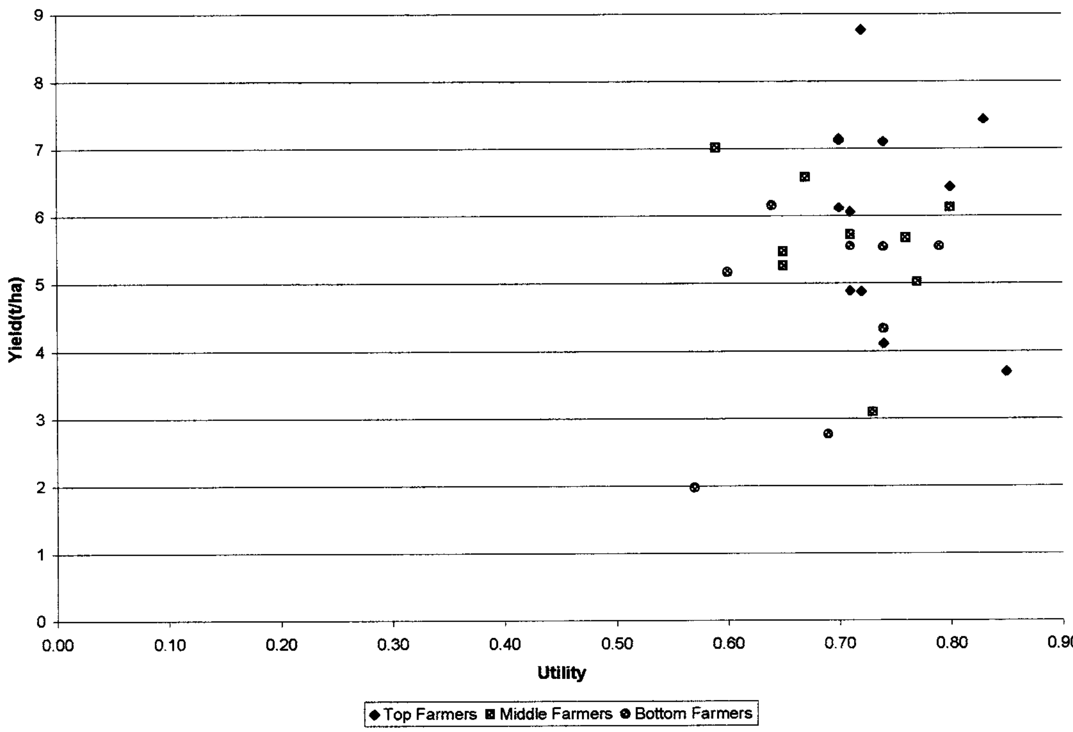

Figure 1. Utility and yield according to farmer location

Table V. Average utility and yield according to location

Location	Average utility	Average yield ($t\ ha^{-1}$)
Top	0.74	6.14
Middle	0.70	5.55
Bottom	0.69	4.62

out that even though there was no direct relationship between utility and yield (correlation coefficient, $r = 0.024$ for Bouake), this was because other factors which affect yield like fertiliser use, farmer's experience, etc., were not considered.

CONCLUSIONS

This study has demonstrated that even where flow monitoring data are not available, it is still possible to evaluate water delivery performance. A rapid semi-quantitative method is proposed which uses fuzzy set theory to process farmers' expressions of their judgement. The method has the advantage of using everyday qualitative expressions, which have been shown (Sheppard, 1954) to be more consistent than arbitrary scoring/weighting schemes. The method allows spatial disaggregation of the performance assessment and avoids subjectivity on the part of the assessor. In the context of service-oriented management of irrigation schemes, it provides a means of assessing performance from the point of view of the key stakeholders (i.e. the farmers).

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