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Improvement of the irrigation performance in Water Users Associations integrating data envelopment analysis and multi-regression models

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ABSTRACT

Irrigation performance assessment is particularly important in the Water Users Associations (WUAs) operating in Calabria (Southern Italy), where collective irrigation service suffers from poor performances both from an operative and economic point of view. For many years Data Envelopment Analysis (DEA) has been proposed for the diagnosis of Water Users Association performance; however, the number and type of related performance indicators must be selected with caution to avoid misleading and unrealistic results.

In this paper, we propose to apply DEA to a limited but significant set of performance indicators and to couple it to Multiple Regression Analysis by Principal Component Regression (PCR). The proposed methods were applied to evaluating the system operation and financial performances of ten of the eleven WUAs operating in Calabria (Southern Italy) to indicate potential improvements.

The analysis of the current performance indicators collected throughout five years (2011–2015) showed that in Calabrian WUAs the irrigation service is underutilised, and water delivered to crops is always in excess; the cost recovery of WUAs is very low, because of staff costs and low fee collection. DEA identified five inefficient WUAs and took the remaining five organisations as reference for performance improvement. The input-oriented DEA coupled to PCR has suggested reducing water usage, management and personnel costs and water fees, by increasing the irrigated area and the irrigation service coverage. The output–output oriented DEA coupled to PCR predicted a high increase of the cost recovery capacity of the inefficient WUAs, but in this case the improved scenario required an abnormal increase (10-fold) of the irrigated area, which may be basically unfeasible.

Overall, the integration of DEA with multi-regression models and their implementation in the case study, using a limited set of easy-to-survey performance indicators, appears to be a powerful and easy tool for decision makers in the irrigation sector.

1. Introduction

In many parts of the world, as, for instance, in Southern Italy and Spain, irrigation water is usually supplied from sources and delivered to farms by Water Users Associations (WUAs). The evaluation of performances in these collective irrigation systems is often neglected, also because it is considered a time-consuming and costly activity, whose results are appreciable only in the long term (Malano et al., 2004). The need for such assessment activities is particularly important in the WUAs operating in Calabria (Southern Italy); here, the collective irrigation service suffers from poor performances both from an operative and economic point of view in a region where agriculture is by far the most important economic sector (Zema et al., 2015). Farmers use large volumes of water to irrigate crops with low requirements or pump groundwater when water supplied from surface water sources is sufficient.

In such contexts, the evaluation of WUA performance is an important management tool to aid in providing a sound irrigation service, because it may support the system management in the identification of the strengths and weaknesses of an organisation and in the improvement of the organisation's performance and productivity, taking into account its objectives (Alcón et al., 2017). One of the most widely-used tools for irrigation performance assessment is "benchmarking", a set of techniques able to identify the gaps between current and achievable performance and making changes to realise a higher standard of performance (Malano et al., 2004). Benchmarking techniques are often applied to Water Users Associations by calculating and processing the so called "performance indicators". These techniques consider different performance indicators, summarising the main management traits to describe and compare the management of the analysed WUAs (Soto-

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Nomenclature

Input parameters/performance indicators

CA	Command area
IA	Irrigated area
AIA	Average irrigated area per farm
NU	Number of users
VIWD	Annual volume of irrigation water delivery
VIWR	Annual Volume of Irrigation Water Required
GRI	Gross revenue invoiced
GRC	Gross revenue collected
MOMC	Total management, operation and maintenance cost
NPI	Total number of personnel engaged in irrigation service
ICR	Irrigated area/command area ratio
WDIA	Annual irrigation water delivery per unit irrigated area
RIS	Annual relative water supply
MOMA	Total management, operation and maintenance cost per unit area
$MOMA^{-}$	Total management, operation and maintenance cost per unit area (without staff costs)
CRR	Cost recovery ratio
CRR^{+}	Cost recovery ratio (with staff costs)
RCP	Revenue collection performance
SUIA	Staffing numbers per unit of irrigated area
CIS	Cost of the Irrigation Service

Water Users Associations

BCSC	Bacini Settentrionali del Cosentino
BMCS	Bacini Meridionali del Cosentino
ICS	Ionio Cosentino
IKR	Ionio Crotonese
TCZ	Tirreno Catanzarese
ICZ	Ionio Catanzarese
TVV	Tirreno Vibonese
TRC	Tirreno Reggino
AIRC	Alto Ionio Reggino
BIRC	Basso Ionio Reggino

García et al., 2013). Benchmarking of collective agencies managing irrigation services is relatively recent and some mathematical/statistical techniques, such as Principal Component Analysis (PCA), Agglomerative Hierarchical Clustering (AHC), Quality Index (QI) calculation, have been applied and validated in different areas worldwide for benchmarking. As regards the Mediterranean basin (which shares similar climatic and structural conditions with Italian agriculture), the following studies of can be cited: Zema et al. (2015) and Rodrìguez-Dìaz et al. (2008) used PCA, AHC and QI in Calabria (Italy) and Andalusia (Spain), respectively; Córcoles et al. (2010, 2012) applied AHC in WUAs of Castilla-La Mancha, Spain; Uysal and Atış (2010) and Koç and Bayazit (2015) processed the performance indicators.

However, if applied to collective irrigation just as a comparative assessment of performance indicators, benchmarking may provide an incomplete picture and such assessment may be difficult to interpret (Malano et al., 2004). Therefore, other tools are required, incorporating diagnostic analysis to identify those factors which majorly contribute to improving the levels of irrigation service performance.

Data Envelopment Analysis (DEA) is a non-parametric, linear programming method that works with input/output ratios to calculate relative efficiencies of organisations. This method has been proposed for benchmarking performance in service sectors, such as irrigation and drainage, because it has a number of advantages. Firstly, DEA has the ability to analyse several inputs and outputs simultaneously and derive an efficiency rating within a set of analysed units; secondly, DEA does not require the development of standards against which efficiency is measured; thirdly, it does not require predetermined production functions to relate inputs and outputs (Malano et al., 2004). However, DEA has so far found little application in irrigation, except for few literature studies (Rodrìguez-Dìaz et al., 2008; Borgia et al., 2013; Frija et al., 2009). To summarise, in irrigation districts of Andalusia (Spain) Rodrìguez-Dìaz et al. (2008) found by DEA great differences in terms of performance between districts with open channel and pressure water delivery systems; water use was more efficient in districts where users were charged per unit of irrigation water consumed. DEA and AHC applied by Borgia et al. (2013) in irrigation schemes of Mauritania demonstrated that, on a technical basis, large schemes performed similarly to small-scale schemes, while these latter showed greater variability of crop yield and technical efficiency, which may indicate a larger margin for improvement. The DEA by Borgia et al. (2013) also helped to identify the specific reference schemes for each low performing scheme. The use of DEA and a Tobit model in WUAs of Tunisia highlighted that management and maintenance are important tasks in determining the overall performance and efficiency (Frija et al., 2009).

Moreover, when applying DEA for benchmarking of irrigation performance, a degree of caution must be exercised in the number and selection of variables to be analysed and processed. As a matter of fact, the selection of variables must be closely related to the objectives of the study and the productive process being evaluated. In addition, there is the risk that the adoption of too many performance indicators would allow DEA to consider all or the majority of the analysed WUAs efficient and thus it would not provide any information about deviations of current situation from optimal management (Malana and Malano, 2006; Alcón et al., 2017). According to Soto-García et al. (2013), the performance indicators should be: (i) easy to obtain from data routinely collected in the WUAs; (ii) mostly oriented towards aspects related to WUA management; and (iii) suitable for the purpose of each specific study. Therefore, a limited set of non-redundant performance indicators − but representative of as many as possible of the productive factors of WUAs − must be chosen for DEA application at the irrigation sector, in order to determine the relative efficiency of a WUA and its position in relation to the optimal situation. Other non-parametric techniques, such as multi-regression models, can be integrated to DEA and applied to the performance indicators not considered by DEA itself.

This paper proposes a novel approach to optimise WUA performance by benchmarking, applying DEA to a limited but significant set of performance indicators, and coupling it to Multiple Regression Analysis by Principal Component Regression (PCR), in order to improve the performance of ten WUAs operating in Calabria. The combination of these techniques is targeted to fully delineate the performances of the inefficient WUAs under an optimised management scenario, taking as reference a sample of efficient WUAs and using the values of a set of operation and financial performance indicators collected throughout five years. This aggregated diagnosis of current status and the prediction of future performance may be useful to the decision-makers to give them a concrete idea about the overall performance of an irrigation scheme vis-à-vis other irrigation schemes (Phadnis and Kuhlshrestha, 2013).

2. Material and methods

2.1. Study area

The region of Calabria is located in the extreme southern part of Italian peninsula. Its climate can be classified as Csa (mild temperate, dry and hot summer, in coastal zones) and Csb (mild temperate, dry and