IRRIGATION AND DRAINAGE
Irrig. and Drain. **65**: 586–591 (2013)
Published online 19 July 2013 in Wiley Online Library (wileyonlinelibrary.com) **DOI**: 10.1002/ird.1754

A STUDY ON SOME PARAMETERS WHICH CAN AFFECT PROJECT IRRIGATION EFFICIENCY IN IRRIGATION NETWORKS†

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ABSTRACT

In this study, some parameters that can affect project irrigation efficiency in irrigation schemes operated and constructed by State Hydraulic Works (DSI) in the Büyük Menderes basin, Turkey, were selected, and the effects on the project irrigation efficiency of these parameters were studied. The selected parameters are irrigation rate, density of irrigation facilities, average farm size, density of distribution scheme, and density of personnel per unit area. In order to determine the possible effects on the project irrigation efficiency of these parameters, SPSS-15 (Statistical Package for the Social Sciences-15) software was used. With this method, partial correlation coefficients related to selected parameters were calculated, and degrees of relationship and possible effects on project irrigation efficiency were determined. Also, in order to determine the parameter values that may make standardize the project irrigation efficiency, parameter coefficients were calculated. Copyright © 2013 John Wiley & Sons, Ltd.

KEY WORDS: irrigation efficiency; irrigation network; SPSS-15; irrigation ratio; parameter

Received 21 June 2012; Revised 21 February 2013; Accepted 21 February 2013

RÉSUMÉ

Dans cette étude, certains paramètres ont été sélectionnés qui sont en mesure d'influer sur l'efficacité de l'irrigation. Les paramètres sélectionnés proviennent de projets d'irrigation exploités et construits par la direction des travaux hydrauliques (DSI) de l'état dans le bassin de Büyük Menderes, Turquie; il s'agit du taux d'irrigation, de la densité des installations d'irrigation, de la taille moyenne des exploitations, de la densité du régime distribution et de la densité du personnel par unité de surface. Afin de déterminer les effets possibles de ces paramètres sur l'efficacité du projet d'irrigation, le logiciel SPSS-15 (Statistical Package for Social Sciences du-15) a été utilisé. Avec cette méthode, les coefficients de corrélation partielle liée à certains paramètres ont été calculés, ainsi que les degrés de relation et les effets possibles sur l'efficacité du projet d'irrigation. En outre, les coefficients de paramètres ont été calculés afin de déterminer les valeurs des paramètres qui permettent de normaliser l'efficacité du projet d'irrigation. Copyright © 2013 John Wiley & Sons, Ltd.

MOTS CLÉS: efficacité de l'irrigation; réseau d'irrigation; SPSS-15; rapport d'irrigation; paramètre

INTRODUCTION

With increasing demand on water resources, project irrigation efficiency is becoming one of the key issues facing irrigation farmers and water managers around the world. There are many benefits to improving irrigation efficiency, including both environmental and economic. These include less stress on water resources, reduced losses of water and nutrients to groundwater and surface water resources, improving production and overall profits, and potentially allowing a greater area to be irrigated with a given volume of water.

Irrigation efficiency is the ratio of the amount of water used by the plants in the irrigation network to the amount taken into the network. Irrigation efficiency is used to express how useful the water is, once it is brought to the fields from its source. Project irrigation efficiency represents the efficiency of the entire physical system and its operating decisions in delivering irrigation water from a water supply

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† Une étude sur quelques paramètres qui peuvent influer sur l'efficacité des réseaux d'irrigation.

source to the target crop. It is calculated by multiplying the efficiencies of water conveyance, distribution and field application (Odhiambo *et al*., 2011). Project irrigation efficiency was developed by the International Commission on Irrigation and Drainage (ICID) by Bos *et al*. (1993). In the Mediterranean region, project irrigation efficiencies range from 30 to 65%, depending on the sophistication of the irrigation system and the on-farm irrigation technology in use (Hamdy, 2007). While project irrigation efficiency is realized as 20% in Yemen, 28% in Thailand and 26% in Mexico, in countries such as Cyprus and Israel, where sprinkler and trickle irrigation technologies are used, efficiency is around 50% and more. Average irrigation project efficiency is around 30% for developing countries. In the United States, it varies from 30 to 80% (Anonymous, 2002). Koç (2005), in his study of the Nazilli, Akçay, Aydın and Söke irrigation networks, which are found in the Büyük Menderes basin, calculated irrigation efficiency by three different methods and found project irrigation efficiency (classic irrigation efficiency) as 43, 45, 61 and 59% respectively. In the 324 irrigation networks (2 053 000 ha), which have been constructed and operated by State Hydraulic Works (DSI), average project irrigation efficiency was found to be 41% (DSI, 2011). The key factors that influence project irrigation efficiency are how well the system is designed and how well it is managed. Irrigation system design is the principal reason for lower than expected levels of efficiency (Lincoln Environmental, 2000).

In this study, some parameters have been chosen that can affect project irrigation efficiency in the irrigation networks constructed and operated in the Büyük Menderes basin, Turkey, by DSI, and the effects of these parameters on irrigation efficiency have been studied.

MATERIALS AND METHODS

In this study, the nine irrigation networks constructed by DSI in the Büyük Menderes basin, Turkey, have been taken as the material to be studied (Figure 1). Some technical and executive properties related to irrigation networks that have been analysed are given in Table I (DSI, 1998–2010). The irrigation networks get their water supply from the dams at Adıgüzel, Kemer and Topçam. The data related to irrigation networks have been taken from 21 Regional Directorate records of the DSI Executive Directorate (DSI, 2006–2010), and some of the data have been acquired from fieldwork. In order to calculate project irrigation efficiency, the data used are the total quantity of irrigation water taken from the irrigation network and crop water requirement values. The total quantity of irrigation water taken from the irrigation networks was measured and calculated by DSI technical personnel. Crop water requirement values

Table I. Irrigation networks studied (DSI, 1998–2010)

Name of the irrigation network	Year of opening	Project irrigation area (ha)	Way of supplying water
Topçam	1985	4 300	Gravity + pump
Akçay	1965	15 000	Gravity
Nazilli	1943	15 000	Gravity
Aydın Plain	1991	20 920	Gravity + pump
Söke Plain	1982	26 000	Gravity
Baklan	1991	42 500	Pump
Sarayköy	1961	10 500	Gravity
Gümüşsu	1992	6 195	Pump
Acıpayam	1997	12 500	Gravity

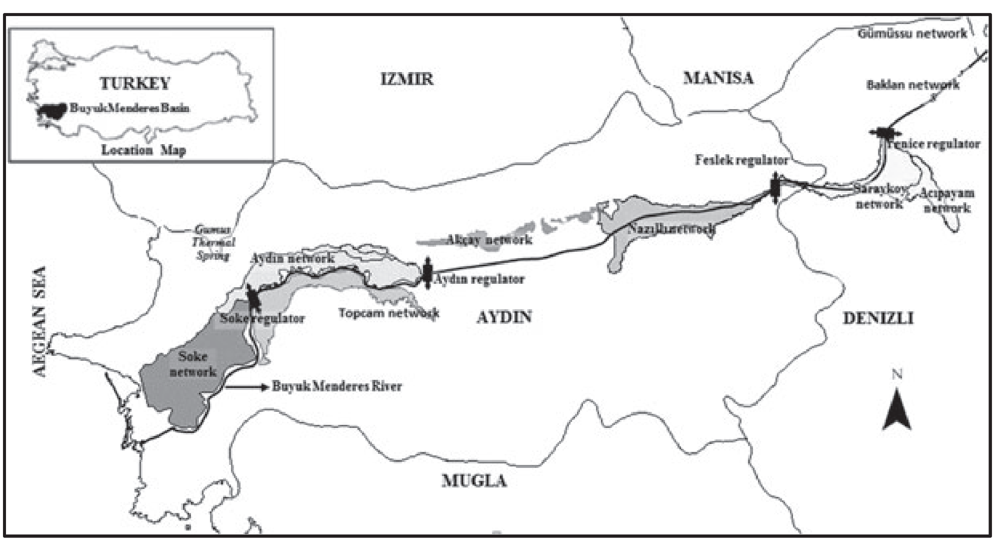

Figure 1. Buyuk Menderes basin and irrigation schemes studied, Turkey

for the irrigation networks researched were taken from DSI records.

In the basin irrigation networks; the effects of a total of five parameters selected to project irrigation efficiency have been studied. The selected parameters include project irrigation efficiency (Y), irrigation ratio (X_1), distribution network density (X_2), personnel density per area (X_3), average farm size (X_4) and irrigation facility density per unit area (X_5). The parameters affecting project irrigation efficiency are determined by the technical personnel operating and managing the irrigation networks of the public irrigation corporation entitled DSI (State Hydraulic Works) in Turkey. The irrigation ratio is to prove actual irrigation area in the project area; distribution network density, the ratio of secondary and tertiary canals distributing irrigation water; personnel density per unit area, the number of personnel operating and managing the irrigation networks; average farm size, size of the fields irrigated in the project area researched; irrigation facility density per unit area, quantity of irrigation facility. Therefore, the five parameters selected for the study are related to project irrigation efficiency. The methods for calculating the parameters and their properties are given in Table II. The primary data used in the study are:

- total project irrigation area (total command area serviced by the irrigation system constructed);
- actual area irrigated (total actual irrigated area during the year);
- the total length of distribution canals (total length of secondary and tertiary canals constructed in the total project irrigation area);
- total canal length (total length of main, secondary and tertiary canals constructed in the total project irrigation area);
- total number of personnel (total number of personnel in the provision of the irrigation service in the project irrigation area, digital data without taking their quality into account).

The SPSS (Statistical Package for the Social Sciences)-15 computer program was used in order to define the possible effects of the chosen parameters on project irrigation efficiency. SPSS-15 is a statistical analysis and data management software package. SPSS-15 can take data from almost any type of file and use them to generate tabulated reports, charts, and plots of distribution and trends, descriptive statistics, and conduct complex statistical analyses. In the study, X_1, X_2, X_3, X_4 and X_5 were taken as independent variables and Y (project irrigation efficiency) was taken as a dependent variable in the data entry to the program. The partial correlation coefficients that are related to the Y dependent variable and the independent variables within themselves, their degrees and partial correlation coefficients related to the dependent variable have been calculated and the standard and the modified regression equations written. Linear regression estimates the coefficients of the linear equation, involving one or more independent variables that best predict the value of the dependent variable. In order to calculate unstandardized and standardized β values for regression equations: unstandardized, the value the model predicts for the dependent variable. Standardized, a transformation of each predicted value into its standardized form. That is, the mean predicted value is subtracted from the predicted value, and the difference is divided by the standard deviation of the predicted values. Standardized predicted values have a mean of 0 and a standard deviation of 1. For each value of the independent variable, the distribution of the dependent variable must be normal. The variance of the distribution of the dependent variable should be constant for all values of the independent variable. The relationship between the dependent variable and each independent variable should be linear, and all observations should be independent. Pearson correlation coefficients have been calculated. The minimum and maximum dependency coefficients have been calculated within the 95% of safety margin for the coefficients.

Table II. Chosen parameters and definitions

Symbols	Parameters	Parameter definition
Y	Project irrigation efficiency (%)	Irrigation water used by plants/Total irrigation water taken to irrigation network
X_1	Irrigation ratio (%)	Actual irrigated area/Total project irrigation area
X_2	Distribution network density (%)	Total length of distribution canals/Total canal length (conveyance + distribution)
X_3	Personnel density per unit area (ha/ pers)	Total project irrigation area/Total personnel number
X_4	Average farm size (ha)	Frequency distribution and random numbers table (DSI records)
X_5	Irrigation facility density per unit area (ha km^{-1})	Total project irrigation area/Total canal length (conveyance + distribution)

Regression equations for unstandardized and standardized β values

$$Y = \alpha + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 \quad (1)$$

$$Y_m = \beta_{1m} X_1 + \beta_{2m} X_2 + \beta_{3m} X_3 + \beta_{4m} X_4 + \beta_{5m} X_5 \quad (2)$$

α (constant), β_1, β_2, β_3,…… (regression coefficients):

$$r_{yx1}, r_{yx2}, r_{yx3}, \ldots\ldots\ldots\ldots, r_{yx5} \quad (3)$$

$$r_{x1x2}, r_{x1x3}, r_{x2x3}, \ldots\ldots\ldots\ldots, r_{x3x4} \quad (4)$$

Table III. Calculated parameter values

Irrigation name	Years	Irrigation efficiency (Y) (%)	Irrigation ratio (X_1) (%)	Distribution network density (X_2) (%)	Personnel density per unit area (X_3) (ha/pers)	Average farm size (X_4) (ha)	Irrigation facility density per unit area (X_5) (ha km^{-1})
Gümüşsu	2006	69	56	91.0	160.0	0.6	23.8
	2007	70	92	92.0	160.0	0.6	21.9
	2008	68	75	92.0	177.8	0.5	21.9
	2009	68	56	92.0	177.8	0.4	21.9
	2010	70	63	92.0	177.8	0.3	21.9
Baklan	2006	61	54	91.0	347.0	0.5	24.0
	2007	70	58	90.0	350.6	1.5	24.0
	2008	71	62	90.0	347.4	1.5	24.0
	2009	70	65	90.0	336.7	1.6	24.0
	2010	70	60	90.0	353.5	1.3	24.0
Sarayköy	2006	52	85	70.0	196.0	0.8	33.6
	2007	65	85	64.0	235.6	0.7	33.6
	2008	60	90	65.0	274.8	0.6	33.6
	2009	51	80	68.0	274.8	0.7	33.6
	2010	54	90	70.0	305.4	0.6	33.6
Acıpayam	2006	18	37	78.0	328.9	0.7	14.6
	2007	65	29	77.0	460.5	0.3	20.4
	2008	56	26	77.0	627.1	0.4	26.1
	2009	52	30	77.0	557.4	0.4	26.1
	2010	44	42	77.0	572.2	0.5	26.9
Topçam	2006	29	43	78.0	187.0	0.8	28.5
	2007	30	35	78.0	187.0	0.7	28.5
	2008	29	32	78.0	187.0	0.6	28.5
	2009	29	36	78.0	187.0	0.7	28.5
	2010	28	37	78.0	187.0	0.7	28.5
Aydın Plain	2006	49	90	88.0	141.5	1.8	21.3
	2007	53	62	88.0	226.0	1.4	23.4
	2008	54	65	88.0	235.7	1.6	23.4
	2009	54	67	88.0	223.0	1.4	23.4
	2010	51	85	88.0	215.1	1.8	26.3
Söke Plain	2006	62	95	91.0	604.6	2.7	37.2
	2007	65	94	91.0	604.7	2.4	37.2
	2008	67	92	91.0	604.7	2.8	37.2
	2009	56	95	91.0	684.2	2.8	37.2
	2010	55	96	91.0	702.7	2.9	37.2
Nazilli	2006	56	95	82.0	255.1	0.7	17.0
	2007	65	90	89.0	205.5	0.6	17.0
	2008	60	94	89.0	205.5	0.7	17.0
	2009	57	93	89.0	211.3	0.6	17.0
	2010	55	92	89.0	227.3	0.5	17.0
Akçay	2006	47	72	76.0	279.3	0.5	41.3
	2007	65	50	76.0	317.0	0.5	41.3
	2008	63	55	76.0	292.1	0.6	41.3
	2009	51	55	76.0	382.1	0.6	41.3
	2010	50	75	76.0	338.6	0.6	41.3

$$\begin{matrix} 1.00 & r_{x1x2} & r_{x1x3} & r_{x1x4} & r_{x1x5} \\ r_{x2x1} & 1.00 & r_{x2x3} & r_{x2x4} & r_{x2x5} \\ r_{x3x1} & r_{x3x2} & 1.00 & r_{x3x4} & r_{x3x5} \\ r_{x4x1} & r_{x4x2} & r_{x4x3} & 1.00 & r_{x4x5} \\ r_{x5x1} & r_{x5x2} & r_{x5x3} & r_{x5x4} & 1.00 \end{matrix} \text{ Pearson correlation matrix} \quad (5)$$

RESULTS AND DISCUSSION

In Table III, the chosen dependent and independent variables related to the irrigation networks have been calculated; in other words, the calculated values for the utilized parameters for the process between 2006 and 2010 have been given.

With the evaluation based on these data, the irrigation ratio (X_1) which is an independent variable, distribution network density (X_2), personnel density per unit area (X_3), average parcel size (X_4) and the variance has been stated as 69.8% for the facility density per area (X_5) to project irrigation efficiency (Y), which is a dependent variable. In other words, the project irrigation efficiency has been shaped as 69.8 % based upon these factors. From this information, $F\,(5, 39) = 5.919$; $p < 0.01$ equation can be formed.

In Table IV, the Pearson correlation matrix of dependency and the degree of relationship between the dependent and independent variables are shown, while the standardized and un-standardized coefficients, the partial correlation coefficients that create the foundation for the regression equation, and the dependency values of the maximum and the minimum of coefficients which are within the 95% of the safety standards, are given in Table V. The modified and standard regression equations and the partial correlation coefficients, which have been obtained through calculations, are as follows:

Standard and standardized regression equation

$$Y_S = -59.40 + 0.299X_1 + 1.04X_2 + 0.027X_3 - 11.1X_4 + 0.398X_5 \quad (6)$$

Standardized regression equation

$$Y_M = 0.507X_1 + 0.643X_2 + 0.323X_3 - 0.610X_4 + 0.233X_5 \quad (7)$$

Partial correlation coefficients

$$r_{yx1} = 0.496, r_{yx2} = 0.504, r_{yx3} = 0.312, r_{yx4} = -0.436, r_{yx5} = 0.218 \quad (8)$$

The project irrigation efficiency is affected mostly by distribution density, irrigation ratio, average farm size, network personnel density per unit area, and network density per unit area. Average farm size (whether the farm is big or with many parts, or small) related to irrigation networks has a decreasing relationship with project irrigation efficiency. The decrease in average farm size affects project irrigation efficiency negatively. Namely, large farm sizes have a positive effect on project irrigation efficiency than smaller farm size. In the same way, an increase in the irrigation ratio and a high irrigation ratio in the examined irrigation project can affect the project irrigation ratio positively. In particular, the land consolidation applications in the irrigation project area bring about the desired network distribution density by having a facility which distributes and conveys to all farms. Therefore, the project irrigation efficiency effects positively as water conveyance and distribution losses reduce. However, irrigation facility density and increase or decrease of network distribution density do not have an effect on the field water application ratio. In the same way, how active the personnel are and their

Table IV. Pearson correlation matrix

	Y	X_1	X_2	X_3	X_4	X_5
Y	1.000	0.424	0.419	0.153	0.159	−0.022
X_1	0.424	1.000	0.257	0.029	0.458	0.093
X_2	0.419	0.257	1.000	0.076	0.465	−0.410
X_3	0.153	0.029	0.076	1.000	0.538	0.404
X_4	0.159	0.458	0.465	0.538	1.000	0.276
X_5	−0.022	0.093	−0.410	0.404	0.276	1.000

Table V. Regression coefficients

	Non-standardized coefficients		Standardized coefficients			β 95% safety margin	
Parameters	β	Standard error	β_m	*t*-test	Importance degree	Lower limit	Upper limit
(α Constant)	−59.400	27.461		−2.163	0.037	−114.945	−3.854
X_1	0.299	0.084	0.507	3.564	0.001	0.129	0.469
X_2	1.035	0.284	0.643	3.647	0.001	0.461	1.609
X_3	0.027	0.013	0.323	2.048	0.047	0.000	0.054
X_4	−11.072	3.661	−0.610	−3.025	0.004	−18.476	−3.668
X_5	0.398	0.286	0.233	1.394	0.171	−0.179	0.976

effectiveness in working in the distribution and the conveyance in irrigation networks, can affect project irrigation efficiency positively; in other words, the usage of irrigation water effectively in accordance with an irrigation plan and having enough personnel will affect project irrigation efficiency in a positive manner. The selection of identified parameters to reach the project irrigation efficiency used in irrigation networks and their compatibility with the project will have a positive contribution in getting and observing the expected benefits from the irrigation project.

CONCLUSIONS AND RECOMMENDATIONS

An irrigation network's project irrigation efficiency is affected by the parameters of irrigation ratio, network distribution density, average farm size, personnel density per unit area and facility density per unit area. As a result, in order to reach project irrigation efficiency values at the planning stage of irrigation networks, it is essential to analyse the examined parameters more intensely and evaluate the modelling work comprising simulation techniques in detail. Defining the values interval related to parameters, and using these values in the planning and project phases, will make it possible to reach the project irrigation efficiency that is targeted for the irrigation network. In this way the utilization of optimal parameter values which are to be used for work that can form a foundation for construction of irrigation networks will allow such planning to create successful results in the project's construction and operation phase.

Construction of irrigation networks should especially not take place in areas where it can be seen that the irrigation ratio will be low. In irrigation areas where the irrigation ratio is low, then the project irrigation efficiency will also be low and the country's resources also become idle.

The realization of land consolidation projects before construction in places where irrigation networks are to be based will allow the irrigation facility amount per unit area to become optimal and will help to reach the expected project irrigation efficiency.

Especially in newly operated irrigation networks, the conveyance of water, its distribution, and having a sufficient /optimum number of personnel who can apply the prepared irrigation programmes in the field, will have a positive contribution towards increasing project irrigation efficiency. Koç *et al*. (2009), in a study which has taken place in the 12 irrigation networks located in the Büyük Menderes basin, have shown that the optimum personnel density for project irrigation efficiency of 50% on average, varies between 137.6 and 287.83 ha per personnel.

Because of the many factors that influence project irrigation efficiency from source to crop (irrigation ratio, network distribution density, average farm size, personnel density per unit area and facility density per unit area), focusing on attaining a reasonable level of irrigation efficiency may be more realistic than trying to calculate irrigation efficiency rigorously.

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