POLİTEKNİK DERGİSİ

JOURNAL of POLYTECHNIC

ISSN: 1302-0900 (PRINT), ISSN: 2147-9429 (ONLINE)

URL: http://www.politeknik.gazi.edu.tr/index.php/PLT/index

Efficiency of irrigation associations in Gediz basin, Turkey

Gediz havzası sulama birliklerinin etkinliği

Yazar(lar) (Author(s)): *Barış YILMAZ, Kazım ATMACA*

Bu makaleye şu şekilde atıfta bulunabilirsiniz (To cite to this article): Yılmaz B. and Atmaca K., “Efficiency of irrigation associations in gediz basin, Turkey”, ***Politeknik Dergisi***, 20(4): 837-842, (2017).

Erişim linki (To link to this article): http://dergipark.gov.tr/politeknik/archive

DOI: **10.2339/politeknik.369025**

Efficiency of Irrigation Associations in Gediz Basin, Turkey

Araştırma Makalesi / Research Article

Barış YILMAZ[1*], Kazım ATMACA[2]

[1] Manisa Celal Bayar University, Manisa Vocational School, Manisa, 45140, Turkey

[2] Manisa Celal Bayar University, Institute of Natural and Applied Sciences, Manisa, 45140, Turkey

(Geliş/Received : 05.12.2016 ; Kabul/Accepted : 17.03.2017)

ABSTRACT

This study concerns the determination of the technical efficiency of irrigation associations (IAs) located in the Gediz Basin in Turkey. For this purpose, 10 IAs operating in the Gediz Basin were evaluated with the use of input oriented DEA model which considers two inputs: water volume supplied (m^3) and total irrigated area (m^2), and one output: the total value of agricultural production (TL). The assurance region approach was used in DEA not only to include the decision makers' preferences into the analysis, but also to limit the inappropriate input/output weights that may affect the efficiency scores. The IAs were evaluated during the period 2009-2011 to conclude the variation of efficiency over the study years. The results showed that, during the study period there was an increment in the number of efficient irrigation districts from 3 to 6. However, Gediz, Mesir and Salihli Right Bank IAs were not able to increase their low efficiency scores. The possible reasons of inefficiency are investigated, and the target volume of irrigation water and irrigated area ensuring the same agricultural production were determined. It is concluded that in inefficient IAs the same agricultural production revenue can be achieved with approximately 60% less water and irrigated area.

Keywords: Data Envelopment Analysis (DEA), efficiency, irrigation, weight restrictions.

Gediz Havzası Sulama Birliklerinin Etkinliği

ÖZ

Bu çalışma, Gediz Havzasında yer alan sulama birliklerinin teknik etkinliklerinin belirlenmesini konu almaktadır. Bu amaçla, Gediz Havzasında faaliyet gösteren 10 sulama birliği girdi odaklı Veri Zarflama Analizi (VZA) modeli kullanılarak değerlendirilmiştir. Analizlerde girdi olarak sulamada kullanılan su miktarı (m^3) ve toplam sulanan alan (m^2), çıktı olarak tarımsal üretimin toplam değeri (TL) kullanılmıştır. VZA'da sadece karar vericilerin tercihlerini analizlere dâhil etmek için değil, aynı zamanda verimlilik puanlarını etkileyebilecek uygun olmayan girdi / çıktı ağırlıklarını sınırlamak için güven bölgesi yaklaşımı kullanılmıştır. Sulama birlikleri 2009-2011 dönemi boyunca değerlendirilmiş ve böylelikle etkinlik değerlerinin yıllara göre değişimi de incelenmiştir. Sonuçlar çalışma süresi boyunca etkin sulama birliği sayısının 3 den 6 ya yükseldiğini, bununla birlikte Gediz, Mesir ve Salihli Sağ Sahil sulama birliklerinin etkinlik değerlerini arttıramadığını göstermiştir. Düşük etkinlik değerlerinin olası nedenleri araştırılmış ve etkin olmayan sulama birliklerinde aynı tarımsal üretimi sağlamak için sulama suyu miktarı ve sulanan alan hedef değerleri belirlenmiştir. Çalışma sonunda etkin olmayan sulama birliklerinin aynı tarımsal üretim gelirini yaklaşık % 60 daha az su ve sulanan alan kullanarak elde edilebileceği sonucuna varılmıştır.

Anahtar Kelimeler: Veri Zarflama Analizi (VZA), etkinlik, sulama, ağırlık kısıtlamalar.

1. INTRODUCTION

Water is an indispensable natural resource for all life. On the other hand, water consumption is steadily increasing due to rapid population growth, global warming, industrial and technological developments. The water shortage affects 11% of the European population and 17% of the land [1]. It is expected that between 2011 and 2050, the world population will increase by 33%, growing from 7.0 billion to 9.3 billion, and food demand will rise by 60% in the same period. Furthermore, it is projected that populations living in urban areas will almost double, from 3.6 billion in 2011 to 6.3 billion in 2050 [2].

In Turkey, agriculture plays a vital role by consuming 73 % of water withdrawals [3] as well as employing 25.5 % of the workforce [4]. This increases the importance of water saving, irrigation efficiency and effective irrigation methods in the agricultural sector. As regards the sustainable management of water resources, the necessity of using modern techniques in new irrigation projects, as well as re-engineering the current irrigation areas is an accepted thought. Such studies should be initiated primarily in inefficient irrigations. The Data Envelopment Analysis (DEA), a linear programming technique, is a popular tool for assessing efficiency of a decision making unit (DMU). By the use of DEA it is possible to decide whether the use of water in an irrigation district is efficient or not.

This study aims to analyze the efficiency of Irrigation Associations (IAs) in Gediz Basin (GB), Turkey. With this aim, the research questions are summarized as (i) Are

*Sorumlu Yazar (Corresponding Author)
e-posta : baris.yilmaz@cbu.edu.tr

the IAs in the GB perform efficiently? (ii) Is the efficient or inefficient IAs change over time? (iii) Can we explain the main reasons for inefficiency? (iv) What are the projected input values to reach the same output? The answers are valuable for water managers to obtain the optimal input(s) configuration, and to take measures for a more beneficial agricultural production.

The previous studies focus on the efficiency analyses in agriculture vary according to the study area, study periods, inputs and outputs, DEA orientation type and DEA envelopment surface that can take the form of constant-return-to-scale (CRS) or variable-return-to-scale (VRS). An overview of studies on technical efficiency of agriculture using the DEA method can be found in [5]. Considering the previous studies, it is evident that the efficiency scores may change with the inputs and outputs used in DEA. However, education of the farm owner, capital expenditure and quality of soil are the main determinants of high efficiency in agriculture, while farm size and farmers' ages are equivocal effect on efficiency [6]. Therefore, confident data of homogenous DMUs should be employed in the analysis, and the results should be investigated in depth through field studies. On the other hand, weight flexibility in DEA allows zero or unacceptable low weights to certain inputs and outputs that is impossible in real life [7-8-9]. However, many researchers deal with operational management are recommended different types of weight restrictions to avoid this flexibility in DEA [10-11-12].

The main studies carried out in the literature as performance evaluation of IAs in GB are summarized below. Silay and Gündüz [13] stated that it is necessary to re-evaluate irrigation projects in GB in the context of a new master plan which should consider the pressurized irrigation system as soon as possible. They also mentioned that it has become increasingly unfavorable from the point of view of the water budget, and that only 63% of the basin can be irrigated in the current conditions. Akkuzu and Mengü [14] assessed system performance for IAs for the years 2002-2008. They have reached the conclusion that the performance of irrigation units has increased over time. Çetinkaya and Barbaros [15] studied the social, economic and climatic indicators and variables affecting water supply and demand in the GB through a water budget simulation model. They examined the use and demand of water in the basin under different response scenarios. They stated that the first step in water basin disposal is to improve existing irrigation systems. Yilmaz et al. [16] used DEA to analyze the efficiency of similar irrigation systems in Buyuk Menderes Basin, and identify the input values required to reach the efficiency values and maximum efficiency of the irrigation units.

In this study, it was aimed to perform efficiency analyzes in the IAs operating in Gediz Basin that covers approximately 110 000 ha irrigation area. For this purpose, 10 IAs were evaluated by conducting an input oriented DEA model which considers two inputs: water volume supplied (m^3) and total irrigated area (m^2), and one output: the total value of agricultural production (TL). The assurance region approach was used in DEA not only to include the decision makers' preferences into the analysis, but also to limit the inappropriate input/output weights that may affect the efficiency scores.

2. METHODOLOGY

Data envelopment analysis (DEA) is a multi-factor productivity analysis model for measuring the relative efficiencies of a homogenous set of decision making units (DMUs). The efficiency score in the presence of multiple input and output factors is defined as:

$$\text{Efficiency} = \frac{\text{weighted sum of outputs}}{\text{weighted sum of inputs}} \qquad (1)$$

Assuming that there are n DMUs, each of with m inputs and s outputs, the relative efficiency score of a test DMU p is obtained by solving the following model proposed by Charnes et al. [17]:

$$\max \quad \frac{\sum_{k=1}^{s} v_k y_{kp}}{\sum_{j=1}^{m} u_j x_{jp}}$$

$$s.t \quad \frac{\sum_{k=1}^{s} v_k y_{ki}}{\sum_{j=1}^{m} u_j x_{ji}} \le 1 \quad \forall I \;\; v_k, u_j \ge 0 \;\; \forall\, k, j, \qquad (2)$$

where

k = 1 to s,

j = 1 to m,

i = 1 to n,

y_{ki} = amount of output k produced by DMU i,

x_{ij} = amount of input j utilized by DMU i,

v_k = weight given to output k,

u_j = weight given to input j.

The fractional program shown as (2) can be converted to a linear program as shown in (3).

$$\max \sum_{k=1}^{s} v_k y_{kp}$$

$$s.t \quad \sum_{j=1}^{m} u_j x_{jp} = 1$$

$$\sum_{k=1}^{s} v_k y_{ki} - \sum_{j=1}^{m} u_j x_{ji} \le 0 \quad \forall I$$

$$v_k, u_j \ge 0 \quad \forall\, k, j. \qquad (3)$$

The above problem is run *n* times in identifying the relative efficiency scores of all DMUs. Each DMU selects input and output weights that maximize its efficiency score. In general, a DMU is considered to be efficient if it obtains a score of 1 and a score of less than 1 implies that it is inefficient.

The two basic DEA models are the Charnes Cooper Rhodes (CCR) model and the Banker Charnes Cooper (BCC) model. These models can be distinguished by the envelopment surface and the orientation. As shown in Figure 1, the envelopment surface can take the form of constant-return-to-scale (CRS) or variable-return-to-scale (VRS) as evaluated in the CCR model and the BCC model, respectively.

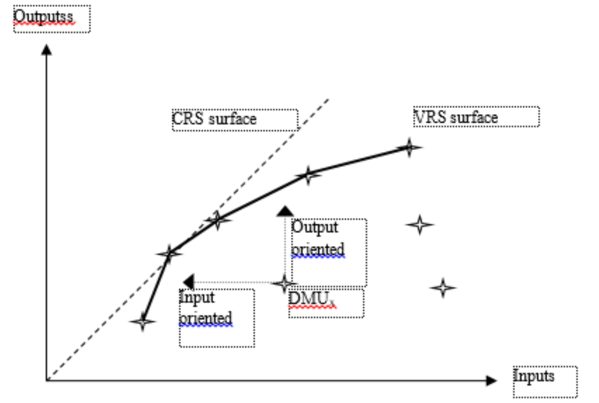

Figure 1. Envelopment surfaces and orientation

The other essential characteristic of DEA models is orientation. The output-oriented model refers to the capacity of a DMU to achieve the maximum volume of production (output) with the available inputs, while the ability to maintain the same capacity of production using a minimum of inputs is known as the input-oriented model. Input-oriented efficiency scores range between 0 and 1.0, and whereas output-oriented efficiency scores range between 1.0 to infinity; in both cases, 1.0 is efficient.

As mentioned previously, Eq.3 allows for unrestricted weight flexibility in determining the efficiency scores of DMUs. This allows units to achieve relatively high efficiencies by indulging inappropriate input and output weights. Weight restrictions allow for the integration of managerial preferences in terms of relative importance levels of various inputs and outputs. Methods for incorporating weight restrictions have been suggested by several researchers [18-19]. Since the use of assurance regions (AR) approach is denoted being more prevalent and reflecting marginal rates of substitution, it is used in this study to include DM preferences in evaluation. The process of setting AR is to define upper and lower bounds for each input and output weight. The lower (α) and upper (β) bounds for each weight can help define constraints that relate the weight values of various factors [9]. These bounds are determined with a series of questions to DMs as Wong and Beasley [12] mentioned: (a) "Do you think that the importance of input measure *i* in evaluating DMUs could be as low (as high) as z%?"; or (b) "Should, as a matter of policy, the importance of input measure *i* in evaluating DMUs be allowed to be as low (as high) as z%?". Once the upper and lower bounds of all inputs are determined, the AR constraints reflect the DM preference range on input weights (Eq. 4) can be added to the linear programming problem, thus the efficiency scores indicate more reliable and reasonable results. Several software is available for DEA to resolve any efficiency problem. Since it gives the input and output weights in pure and virtual form the software EMS [20] is used in this study.

$$v_i \geq \frac{\alpha_i}{\beta_j} v_j$$

$$v_i \leq \frac{\beta_i}{\alpha_j} v_j \qquad (4)$$

3. DATA AND ANALYSIS SETUP

The Gediz Basin is located at the interval of 38° 01′- 39° 13′northern latitude and 26° 42′-29° 45′ eastern longitude (Figure 2). It has a typical Mediterranean climate with hot, dry summers and cool winters. In the basin, mean annual temperature and mean annual precipitation are 15.6°C and 635 mm, respectively. January and February are the wet, and July and August are the driest months. 75% of the total annual precipitation is observed between November and March. The basin covers an area of about 110 000 ha which are subject to extensive agricultural practices with large irrigation schemes. The main crops cultivated are cotton, maize, grape, vegetables and cereals. Due to climatic conditions, irrigation is most important requirement of agriculture which is the main economic activity in the basin. In the basin, irrigation uses a large share of the surface water resources in the basin with a total about 660 10^6 m^3.

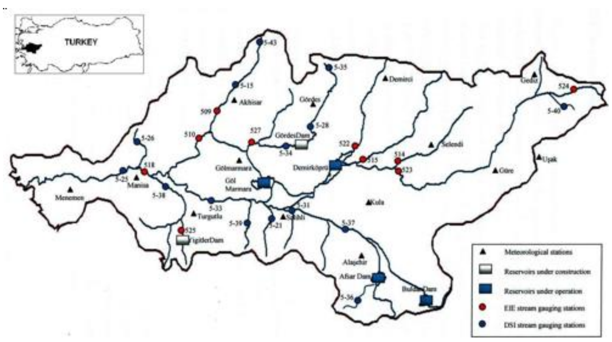

Figure 2. The Gediz Basin

In this study, the technical efficiencies of the 10 IAs operated in the basin are investigated. Data were obtained from the crop census published by DSI (General Directorate of State Hydraulic Works). Analyses were carried out using 2009-2011 data to evaluate if the efficiency scores of IAs change over the study period, or not. The output is defined as the total production value in Turkish currency (PV-10^6 TL) while inputs are water volume used (WU-10^6 m^3) and area irrigated (IR-10^6 m^2). The input-oriented BCC (VRS) model was used in the analyses since the current situation of agriculture in the basin require more efficient use of water. The analyses were performed with the weight limits which are obtained by the conversations with the local water managers. The additional constraints for the calculations can be summarized as: $0.30\ v_1 \geq 0.70\ v_2$ and $0.20\ v_1 \leq 0.80\ v_2$, where v_1 and v_2 indicates weights of water used and area irrigated, respectively. The data obtained by a normalization process were used in the analyses for more efficient computational execution [9]. Dyson et al. [21] suggest that to achieve a reasonable level of discrimination, the practitioner needs the number of units to be at least *2*m*s* where *m*s* is the product of the number of inputs and number of outputs, and state that subsets of the inputs or outputs are often correlated. In this study, the number of inputs are 2 and the number of output is 1. The number of DMUs used in the analyses are 10, and it is greater than the required min $_{DMU}$ = 2*2*1= 4. The correlations between inputs and outputs are given in Table 1, where the strong and positive correlation can be noted for all study years. With this model composition, it is in accordance with given references.

The efficiency score of Salihli LB, which was 0.538 in 2009, has increased to 0.660 in 2010 and to 1 in 2011. Similar increases were also observed in Ahmetli and Sarikiz. It can be said that the increase in the unit price of grapes, which is the largest product in the crop pattern of these IAs, caused the efficiency scores to increase.

In Menemen RB, it was determined that the 100% efficiency score in 2009 decreased to 73.8 % in 2010 and to 56.3 % in 2011. Between 2009 and 2011, despite the increase in irrigated area, the stable state of production value can be addressed as the main reason for efficiency decrease in Menemen RB.

Salihli RB, Gediz and Mesir were the ineffective irrigation associations in all study period. When Salihli and Gediz are analyzed, it is seen that the efficiency score is lower than 50 % in all three years and the highest score in Mesir is 75.4 %. Considering the 2011 baseline, the DEA model suggests the amount of water used in the irrigation should be reduced to 16.08 10^6 m^3 for Gediz, which has the lowest efficiency value among the irrigation associations. In other words, it has been determined that the same total production value can be achieved by providing a water saving of 62 % and reducing the irrigation areas to 15.23 10^6 m^2. It is concluded that, for all *chronically* inefficient irrigation associations (Gediz, Mesir and Salihli RB), the water volume used in irrigation as well as the irrigated area should be decreased approx. 60% to increase the efficiency scores.

Table 1. Correlations between inputs and outputs in study years

Correlation coefficients, r	2009		2010		2011	
	IR	PV	IR	PV	IR	PV
WU	0.91	0.86	0.95	0.93	0.96	0.86
PV	0.96	1.00	0.96	1.00	0.86	1.00

4. RESULTS AND DISCUSSION

The results of the DEA model including the data, the efficiency scores and the target input values to achieve the same output are given in Table 2, where the efficient IAs are highlighted. It is observed that the number of efficient irrigation associations increased from 3 to 6 in 2011. In addition, Gökkaya and Menemen LB (Left Bank) are marked as efficient in all three years while Turgutlu has increased its efficiency score from 0.710 to 1 in 2010 and 2011. When the crop pattern in the efficient IAs are investigated, Gökkaya and Menemen LB are seen to have increased density of cotton and grape which have relatively higher prices. This is concluded as the main reason for the efficiency scores in relevant IAs. On the other hand, Menemen LB has the largest irrigation ratio (85 %) among the units in the basin, and that is another conceivable reason for its high efficiency.

According to the results of the study, it can be said that the efficiencies of IAs, excluding Gediz, Mesir and Salihli RB, were changed from year to year. Here, the main factor is the proportion of grape and cotton in the crop pattern. Since these crops have high commercial values, they affect the efficiency scores. However, in inefficient IAs maize covers a large amount of the crop pattern (approx. 75 %). With its high water requirement and lower market value, the efficiency scores are quite low in IAs where the maize cultivation is dominant. So, the change of crop pattern will be a valuable measure for increasing the efficiency among the measures to be taken. In addition, the water managers should also consider the measures that will save irrigation water as a priority.

Table 2. DEA results of IAs for study years

IAs		WU (10^6 m^3)	IR (10^6 m^2)	PV (10^6 TL)	Efficiency	Projected values		
						WU	IR	PV
2009								
1	Salihli RB	54.00	45.61	37.20	0.358	19.34	16.34	37.20
2	Salihli LB	51.00	53.00	54.20	0.538	27.42	28.49	54.20
3	Ahmetli	15.00	15.10	16.74	0.531	7.97	8.02	16.74
4	**Gokkaya**	**1.80**	**6.25**	**6.74**	**1.000**	**1.80**	**6.25**	**6.74**
5	Turgutlu	34.00	38.86	48.91	0.710	24.15	27.60	48.91
6	Sarikiz	73.00	74.40	75.72	0.652	47.62	48.53	75.72
7	Gediz	31.00	31.56	23.54	0.371	11.51	11.71	23.54
8	Mesir	42.00	51.77	53.51	0.620	26.02	32.07	53.51
9	**Menemen RB**	**27.00**	**34.94**	**56.13**	**1.000**	**27.00**	**34.94**	**56.13**
10	**Menemen LB**	**79.00**	**128.26**	**118.14**	**1.000**	**79.00**	**128.26**	**118.14**
2010								
1	Salihli RB	73.40	74.40	60.19	0.479	35.17	35.65	60.19
2	Salihli LB	50.00	53.14	57.31	0.660	33.00	35.07	57.31
3	Ahmetli	15.00	14.60	21.09	0.694	10.41	10.14	21.09
4	**Gokkaya**	**1.80**	**6.21**	**9.16**	**1.000**	**1.80**	**6.21**	**9.16**
5	**Turgutlu**	**35.00**	**38.29**	**60.86**	**1.000**	**35.00**	**38.29**	**60.86**
6	Sarikiz	73.00	81.12	81.66	0.810	59.12	65.70	81.66
7	Gediz	31.00	34.60	26.27	0.430	13.32	14.87	26.27
8	Mesir	41.00	58.93	56.71	0.754	30.93	44.46	56.71
9	Menemen RB	39.00	46.93	51.70	0.738	28.79	34.64	51.70
10	**Menemen LB**	**100.00**	**155.66**	**124.77**	**1.000**	**100.00**	**155.66**	**124.77**
2011								
1	Salihli RB	72.10	65.04	66.83	0.403	29.03	26.18	66.83
2	**Salihli LB**	**51.80**	**56.08**	**97.76**	**1.000**	**51.80**	**56.08**	**97.76**
3	**Ahmetli**	**11.00**	**14.92**	**31.71**	**1.000**	**11.00**	**14.92**	**31.71**
4	**Gokkaya**	**1.10**	**4.38**	**9.52**	**1.000**	**1.10**	**4.38**	**9.52**
5	**Turgutlu**	**31.00**	**36.87**	**75.48**	**1.000**	**31.00**	**36.87**	**75.48**
6	**Sarikiz**	**79.80**	**84.94**	**109.49**	**1.000**	**79.80**	**84.94**	**109.49**
7	Gediz	42.40	40.17	40.15	0.379	16.08	15.23	40.15
8	Mesir	52.10	61.27	80.60	0.685	35.66	41.94	80.60
9	Menemen RB	38.00	50.91	55.23	0.563	21.39	28.66	55.23
10	**Menemen LB**	**100.80**	**138.59**	**115.96**	**1.000**	**100.80**	**138.59**	**115.96**

5. CONCLUSION

In this study, an input-oriented and weight restricted DEA model is used to investigate technical efficiencies of the irrigation associations operating in the Gediz Basin. The results indicate that efficiency scores of some IAs are continuously low. This implies that significant actions are needed to increase the efficiency levels especially in Gediz, Mesir and Salihli RB irrigation associations. An important finding of the study is that the same agricultural production revenue can be achieved by less water and less irrigated land; however, modern irrigation methods and high profitability crops should be used in the future strategies. On the other hand, there is an increment in the number of efficient IAs in the last years. Efforts to increase irrigation ratio, agricultural training programs and subsidies for effective use of water resources will ensure the performance improvement and stronger socio-economic structure.

The DEA is determined as a highly useful tool to assess irrigation efficiency. The weight restricted DEA models allow for the integration of decision maker(s) preferences in terms of relative importance levels of various inputs and outputs. The analysis presented in this study can be improved by considering the factors for example the soil quality, the age and education levels of the farmers. The further studies can be expanded for the other basins in Turkey, in this way the policymakers can benefit from the findings in order to obtain the current status of agricultural efficiency in Turkey; moreover, the results can be compared with the agricultural efficiencies in European countries.

REFERENCES

[1] EU, "Water scarcity and drought in the European Union", ***EU Publications Office***, (2010). http://ec.europa.eu/environment/water/quantity/pdf/brochure.pdf

[2] UN, "United Nations World Water Development Report, Water and Jobs", ***United Nations Educational, Scientific and Cultural Organization***, Paris, (2016). http://www.unesco.org/new/en/natural-sciences/environment/water/wwap/wwdr/2016-water-and-jobs/

[3] DSI, "Devlet Su İşleri Genel Müdürlüğü 2015 Yılı Faaliyet Raporu", ***General Directorate of State Hydraulic Works (DSI)***, Ankara, (2015).

http://www.dsi.gov.tr/docs/stratejik-plan/dsi-2015-faaliyet-raporu.pdf?sfvrsn=2

[4] TOBB, "Türkiye Tarım Sektörü Raporu", ***The Union of Chambers and Commodity Exchanges of Turkey (TOBB)***, 2014/230, Ankara, (2014).

http://www.tobb.org.tr/Documents/yayinlar/2014/turkiye_tarim_meclisi_sektor_raporu_2013_int.pdf

[5] Kočišová K., "Application of the DEA on the measurement of efficiency in the EU countries", ***Agricultural Economics - Czech***, 61: 51-62, (2015).

[6] Nowak A., Kijek T., Domańska K., "Technical efficiency and its determinants in the European Union agriculture", ***Agricultural Economics - Czech,*** 61: 275-283, (2015).

[7] Belton V., Vickers S.P., "Demystifying DEA-A visual interactive approach based on multiple criteria analysis", ***Journal of Operational Research Society***, 44 (9): 883-896, (1993).

[8] Li X.B., Reeves G.R., "A multiple criteria approach to data envelopment analysis", ***European Journal of Operational Research***, 115: 507-517, (1999).

[9] Sarkis J., "A comparative analysis of DEA as a discrete alternative multiple criteria decision tool", ***European Journal of Operational Research***, 123: 543-557, (2000).

[10] Allen R., Athanassopoulos A., Dyson R.G., Thanassoulis E., "Weight restrictions and value judgements in data envelopment analysis: Evolution, development and future directions", ***Annals of Operations Research***, 73: 13-34, (1997).

[11] Lins M.P.E., Moreira da Silva A.C., Lowell C.A.K., "Avoiding infeasibility in DEA models with weight restrictions", ***European Journal of Operational Research***, 181: 956-966, (2007).

[12] Wong Y.H.B., Beasley J.E., "Restricting weight flexibility in data envelopment analysis", ***Journal of Operational Research Society***, 41(9): 829-835, (1990).

[13] Silay A., Gündüz O., "Demirköprü baraj gölü su bütçesi ve sulama performans değerlendirmesi", ***V. Ulusal Hidroloji Kongresi***, 103-112, Ankara, (2007).

[14] Akkuzu E., Mengü G.P., "Aşağı Gediz Havzası sulama birliklerinde karşılaştırmalı performans göstergeleri ile sulama sistem performansının değerlendirilmesi", ***Ege Üniversitesi Ziraat Fakültesi Dergisi***, 49 (2): 149-158, (2012).

[15] Çetinkaya C.P., Barbaros F., "Su yönetimi senaryoları ile Gediz nehri yıllık su bütçesi performansının değerlendirilmesi", ***TMMOB 2. Su Politikaları Kongresi***, 323-334, Ankara, (2008).

[16] Yilmaz B., Yurdusev M.A., Harmancioglu N.B., "The assessment of irrigation efficiency in Buyuk Menderes Basin", ***Water Resources Management***, 23: 1081-1095, (2009).

[17] Charnes A., Cooper W.W., Rhodes E., "Measuring the efficiency of decision-making units", ***European Journal of Operational Research***, 2: 429-444, (1978).

[18] Thanassoulis E., Allen R., "Simulating weight restrictions in data envelopment analysis by means of unobserved DMUs", ***Management Science***, 44 (4): 586-594, (1998).

[19] Thompson R.G., Langemeier L.N., Lee C.T., Thrall R.M., "The role of multiplier bounds in efficiency analysis with application to Kansas farming", ***Journal of Econometrics***, 46: 93-108, (1990).

[20] Scheel H., "EMS: Efficiency Measurement System User's Manual", ***Universität Dortmund***, Dortmund, Germany, (2000).

[21] Dyson R.G., Allen R., Camanho A.S., Podinovski V.V., Sarrico C.S., Shale E.A., "Pitfalls and Protocols in DEA", ***European Journal of Operational Research***, 132: 245-259, (2001).