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Ranking irrigation schemes based on principle component analysis in the arid regions of Turkey

S. Kartal[1], H. Değirmenci[2,*] and F. Arslan[2]

[1]University of Akdeniz, Kumluca Vocational School, Plant and Animal Production Department, TR07350, Antalya, Turkey
[2]University of Kahramanmaraş Sütçü İmam, Faculty of Agriculture, Biosystem Engineering Department, TR46040, Kahramanmaraş, Turkey
[*]Correspondence: hdegirmenci46@gmail.com

Abstract. Water is a scarce resource and thus irrigation schemes in arid regions have become more important. The irrigation sector which uses most of the water resources has to cope with global warming, disasters and water scarcity around the world, particularly in the Mediterranean countries, including Turkey. Irrigation schemes, which were built by DSI (State Hydraulic Works) and whose operation and maintenance management was transferred to water user associations, play a crucial role in irrigated agriculture in Turkey. In order to improve the performance, weakness and strengths of irrigation schemes are determined by performance indicators (system operation, financial and production efficiency) which show the overall information about them. In the present study, seven irrigation schemes located in an arid region of central Anatolia were chosen to assess the irrigation performance using principal component, correlation and cluster analysis while quality index showed the rank of the irrigation schemes. We found that the average total annual volume of irrigation supply was 7,648.58 m^3 ha^{-1} and the average relative water supply was 1.91 during the 11 years between 2006 and 2016. In this region, higher inverse correlations were due to using surface irrigation methods (51.3%). As of 2017, the irrigation schemes have weak water distribution systems, on an average, consisting of 55.5% open canals, 22.5% canalette and only 10% pipes. According to the quality index, financial and system operation indicators are more effective than that of production efficiency indicators. In conclusion, average irrigation ratio (55.68%) can be increased by improving the water distribution system, and the technology used on both management and farm levels.

Key words: Principal components analysis, irrigation performance indicators, irrigation schemes, quality index.

INTRODUCTION

Water is the most important and an indispensable resource for supporting life. Due to both climatic changes and anthropogenic causes, the amount of available water on earth is decreasing over time. Hence, it is necessary to maximise the output from all the water that is still available. A research conducted by the National Aeronautics and Space Administration of the United States Federal Government (NASA) showed that the consumption of available water in the world is increasing at a higher rate than that of its rate of replenishment (Anonymous, 2017a).

The scarcity of water resources necessitates the efficient use of water in agriculture. In this respect, it is mandatory to choose efficient irrigation methods and systems in agricultural systems, and to increase the skills and training of the labour force in the agricultural field (Değirmenci, 2004).

Turkey is not a water-rich country where the average annual precipitation is about 643 mm and groundwater potential is approximately 112 billion m^3 $year^{-1}$ out of which 44 billion m^3 of water is consumed. The amount of water available per capita is approximately 1,519 m^3 annually indicating that Turkey is already facing a water deficit (DSI, 2017). Turkey spans over 78 million ha and, 28 million ha, constituting about one-third of the land area, is under cultivation. Studies show that it is possible to economically irrigate approximately 8.5 million ha of land with the existing water potential. Within this area, 5.9 million ha of land is equipped for irrigation. The responsibility of the operation and maintenance of irrigation networks in Turkey has been transferred to water user associations since 1993. Approximately 86% of the area open to total irrigation in Turkey has been transferred to irrigation unions, 5.9% to cooperatives, 5.5% to municipalities and 1.6% to village legal entities (Anonymous, 2017b). The transfer of responsibilities of the operations, maintenance and management of the irrigation facilities, is aimed to protect the facilities, carry out timely maintenance, reduce maintenance costs and to achieve fair water distribution. However, research has indicated that the above aims have not been achieved (Kartal, 2018).

Evaluation of the performance of irrigation schemes and an assessment of the current situation is of great importance in determining whether the targets have been achieved. For this purpose, performance evaluation studies should be performed for all the irrigation schemes including an assessment of the irrigation management. The performance of the irrigation schemes operated by the DSI in Turkey is monitored and evaluated annually. Performance indicators that are used include water supplied to users, irrigation efficiency, cost and benefit. However, the information available from the monitoring and evaluation efforts is not sufficient. Hence, the performance of the irrigation systems has not adequately been determined. As a result, efforts are used to establish a performance indicator set compatible with that used for irrigation systems in other countries (Nalbantoğlu & Çakmak, 2007).

Several studies such as Bareng et al. (2015) and Bumbudsanpharoke & Prajamwong (2015) have been carried out to evaluate the performance of irrigation networks. Alcon et al. (2017) evaluated five irrigation schemes in the Segura river basin of south-eastern Spain using data from 2002–2010 with a total of 10 water use efficiency indicators, energy use and agricultural production efficiency indicators. They used the panel data regression model in the evaluation. Using their approach, Arslan & Değirmenci (2018) evaluated the performance of Kahramanmaraş left bank irrigation scheme in Turkey using RAP-MASSSCOTE (Mapping System and Services for Canal Operation Techniques) with both management and operational indicators. Zema et al. (2018a) evaluated 10 water user associations using performance indicators in Calabria region in southern Italy. Data enveloping analysis and principal components analysis were used in the statistical evaluation. Rodriguez-Diaz et al. (2008) evaluated nine water user associations with a new methodology called quality index to determine overall performance of 27 system operations, production efficiency and financial indicators in the Spanish Andalusian region. Corcoles et al. (2011) evaluated seven water user associations in the Castilla - La Mancha region of Spain, using the basic components and cluster analysis using data from 2006–2008. A total of 79 financial activity, system operating activity, production activity and environmental activity indicators were used in the evaluation. Energy indicators were also used depending on features such as conceptual, operational, efficiency and quality of supply.

The effective use of water resources is particularly important in arid regions such as central Anatolia. In order to achieve this goal, irrigation schemes, responsible for water management in the agricultural areas where 70% of water is consumed, should be evaluated. Performance indicators aid in the evaluation and provide the irrigation managers the direction of the current situation of the irrigation schemes.

The main aim of this current study is to evaluate seven irrigation schemes in the Anatolia region of central Turkey using 14 performance indicators (water distribution, finance and productivity) with the data from 2008 to 2015. Quality index, a statistical method, was chosen to rank irrigation schemes based on the overall performance score.

MATERIALS AND METHODS

Çumra, Ayrancı, Altınapa, Ivriz, Karaman, Ilgin and Kıreli irrigation schemes located in the central Anatolian region were selected. Data from 2008 to 2015 including the command area, irrigated area, water diverted or pumped from reservoir, irrigation water requirement, operation-maintenance cost, total annual expenditure and production value were obtained from DSI (State Hydraulic Works) monitoring and evaluation reports. General features of the irrigation schemes are presented in Table 1.

Table 1. General features of the irrigation schemes

Irrigation schemes	First operation year	Command area (ha)	Water diversion	Main crops
Çumra	1912	59,650	Gravity-pumped	Grain-Sugar beet-Sunflower
Ayrancı	1962	4,600	Gravity	Cereals-Fruit-Forage crops
Altınapa	1968	1,015	Gravity	Fruit-Vegetable-Cereals
İvriz	1983	36,108	Gravity-pumped	Cereals-Corn-Sunflower
Karaman	1988	15,040	Gravity-pumped	Cereals-Corn-Fruit
Ilgın	1993	5,214	Pumped	Sugar beet-Cereals-Corn
Kıreli	2002	1,0511	Gravity-pumped	Sugar beet-Corn-Forage crops

Calculation of performance indicators

Comparison indicators of Malano & Burton (2001) and Molden et al. (1998) were used in the calculation (formulae and correction factors) of performance indicators in the current study (Table 2). In the calculation of output, the Central Bank's average dollar rate was used for the local currency for the relevant year in Turkey.

Statistical evaluation

According to Rodriguez-Diaz et al. (2008) and Zema et al. (2015), the quality index, which is present in all indicators, can be calculated to give overall performance as a score. To calculate the score of the irrigation schemes considering performance indicators, the following procedure which consists of the factor analysis was used:

1- Calculating min, max and mean values of the land fragmentation indices for irrigation schemes.

2- Normalising the performance indicators from 0 to 1. The aim of this step is to normalise the smallest value to 0, the maximum value to 1 and to spread all other data to the range of 0–1.

3- Applying the principal component analysis to the performance indicators which were calculated according to Table 2 for each irrigation scheme.

Table 2. Calculation of the performance indicators

	Indicators	Formula	Code	Correction factor
Water distribution	Irrigation ratio (%)	$\frac{\text{Irrigated area} \cdot 100}{\text{Command area}}$	A	+1
	Annual irrigation water supplied per unit irrigated area ($m^3\ ha^{-1}$)	$\frac{\text{Annual irrigation water supplied}}{\text{Irrigated area}}$	B	-1
	Annual irrigation water supplied per unit command area ($m^3\ ha^{-1}$)	$\frac{\text{Annual irrigation water supplied}}{\text{Command area}}$	C	-1
	Annual relative water supply	$\frac{\text{Annual irrigation water supplied}}{\text{Annual irrigation water requirement}}$	D	-1
Financial	Total MOM cost per unit irrigated area ($ ha^{-1})	$\frac{\text{Total MOM cost}}{\text{Irrigated area}}$	E	-1
	Total MOM cost per unit command area ($ ha^{-1})	$\frac{\text{Total MOM cost}}{\text{Command area}}$	F	-1
	Total MOM cost per unit irrigation water supplied to users ($ m^{-3})	$\frac{\text{Total MOM cost}}{\text{Annual irrigation water supplied}}$	G	-1
	Total cost per unit irrigated area ($ ha^{-1})	$\frac{\text{Total cost}}{\text{Irrigated area}}$	H	-1
	Total cost per unit command area ($ ha^{-1})	$\frac{\text{Total cost}}{\text{Command area}}$	I	-1
	Total cost per unit irrigation water supplied ($ m^{-3})	$\frac{\text{Total cost}}{\text{Annual irrigation water supplied}}$	J	-1
Productivity	Output per unit irrigated area ($ ha^{-1})	$\frac{\text{Total annual value of agricultural production}}{\text{Irrigated area}}$	K	+1
	Output per unit command area ($ ha^{-1})	$\frac{\text{Total annual value of agricultural production}}{\text{Command area}}$	L	+1
	Output per unit irrigation water supplied to users ($ m^{-3})	$\frac{\text{Total annual value of agricultural production}}{\text{Annual irrigation water supplied}}$	M	+1
	Output per unit irrigation water requirement ($ m^{-3})	$\frac{\text{Total annual value of agricultural production}}{\text{Annual irrigation water requirement}}$	N	+1

*MOM: Maintenance, operation and management; A: Irrigation ratio (%); B: Annual irrigation water supplied per unit irrigated area ($m^3\ ha^{-1}$); C: Annual irrigation water supplied per unit command area ($m^3\ ha^{-1}$); D: Annual relative water supply; E: Total MOM cost per unit irrigated area ($ ha^{-1}); F: Total MOM cost per unit command area ($ ha^{-1}); G: Total MOM cost per unit irrigation water supplied to users ($ m^{-3}); H: Total cost per unit irrigated area ($ ha^{-1}); I: Total cost per unit command area ($ ha^{-1}); J: Total cost per unit irrigation water supplied ($ m^{-3}); K: Output per unit irrigated area ($ ha^{-1}); L: Output per unit command area ($ ha^{-1}); M: Output per unit irrigation water supplied to users ($ m^{-3}); N: Output per unit irrigation water requirement ($ m^{-3}).

4- Calculating % weight of the coefficients obtained from principal component analysis.

5- Correcting coefficient values according to the correction factor (Table 2) of the indices.

6- Calculation of the weighted indicator values.
7- Calculation of the overall holding scores.

RESULTS AND DISCUSSION

The calculated performance indicators' minimum, maximum, average and standard deviation values of the irrigation schemes are shown in Table 3. Average value of irrigation ratio (A) was the highest (100%) in the Ayrancı and lowest (9.16%) in the Altınapa irrigation scheme. The average performance of the irrigation schemes in Turkey was 62% in 2017 (DSI, 2017). In this context, irrigation schemes with an irrigation ratio lower than 62% are insufficient in terms of the irrigated area in Turkey. Annually, irrigation water supplied per unit irrigated area (B) was highest (63,440.86 m^3 ha^{-1}) while Altınapa irrigation scheme had the lowest (190.65 m^3 ha^{-1}). Annual relative water supply (D) of 0.43 was the lowest in Kıreli and the highest (13.63) in Altınapa. Annual relative water supply values in Turkey were found to be between 1.55 and 1.98 in Akıncı irrigation scheme (Nalbantoğlu & Çakmak 2007), and according to results of Değirmenci (2001) it was changed from 0.91 to 7.15 in the irrigation schemes that were transferred. Average total MOM cost per unit irrigated area was the highest ($ 499.25 ha^{-1}) in Kıreli and the lowest ($ 4.41 ha^{-1}) in the Altınapa irrigation scheme. On the other hand, average total MOM cost per unit command area was the highest ($ 143.01 ha^{-1}) in Karaman and the lowest ($ 1.44 ha^{-1}) in the Altınapa irrigation scheme. Total MOM cost per unit area did not show high performance. In this current study, we took into consideration this indicator to be as low as possible, and the lower values of the indicator showed higher performance. However, some modernisation expenditure could have increased the indicator, and the higher values of the indicator could have increased the performance. Average total cost per unit irrigated area (H) was found to be the highest ($ 5,737.77 ha^{-1}) in Kıreli and the lowest ($ 237.28 ha^{-1}) in Karaman. Total cost per unit irrigation water supplied (J) shows that the Altınapa irrigation scheme had the lowest performance while Kıreli had the highest. Output per unit irrigated area and per unit irrigation water requirement was the highest in the Altınapa and the lowest in the Ayrancı irrigation scheme. These observations suggest that the Altınapa irrigation scheme has the best performance in terms of productive indicators.

Principal component analysis

The Kaiser-Mayer-Olkin (KMO) and the Bartlett test were applied to understand whether the data set (performance indicators) is appropriate for the basic component analysis. It is basically a test for sampling adequacy. Based on the results of the KMO and the Bartlett test shown in Table 4, the dataset was found to be suitable for the principal component analysis.

Table 4 shows that treatments D and B are in the second group while M, N and K are in the third group. According to the results it may be suggested that the first component, which explains most of the variation, represents indicators related to water in just one variable which is the first group.

Table 3. Descriptive statistics of performance indicators

Indicator	Code*	A	B	C	D	E	F	G	H	I	J	K	L	M	N
Çumra	Min.	84.58	3,686.60	3,262.76	1.20	45.83	40.79	0.01	620.39	552.27	0.07	2,367.27	2,107.37	0.25	0.41
	Max.	97.61	1,1873.12	10,231.70	3.25	108.52	93.52	0.01	939.88	805.61	0.22	3,071.11	2,764.53	0.73	1.00
	Mean	88.38	8273.43	7,283.13	2.34	75.07	66.23	0.01	792.81	700.21	0.11	2,690.72	2,376.93	0.37	0.78
	Ss.	3.93	2,594.73	2,206.48	0.74	21.01	18.16	0.00	86.57	78.68	0.05	218.57	207.22	0.16	0.16
Ayrancı	Min.	17.76	3,817.50	1,086.96	1.25	4.51	1.70	0.00	421.26	421.26	0.05	1,247.64	267.35	0.15	0.22
	Max.	100.00	8,913.04	8,913.04	2.95	342.16	65.18	0.06	2,810.59	560.67	0.46	5,188.23	3,945.97	1.08	1.83
	Mean	79.73	6,598.25	5,404.89	1.88	65.80	29.95	0.01	937.46	482.40	0.15	2,946.03	2,287.06	0.51	0.90
	Ss.	32.33	1,620.69	2,813.58	0.51	107.04	26.59	0.02	837.15	40.82	0.14	1,337.57	1,217.79	0.32	0.50
Altınapa	Min.	9.16	9,419.08	1,379.31	2.12	4.41	1.44	0.00	491.28	230.75	0.03	2,864.85	394.90	0.07	0.64
	Max.	83.74	63,440.86	15,665.02	13.63	99.03	70.13	0.01	2,875.29	411.42	0.22	8,921.87	4,549.63	0.72	2.06
	Mean	28.49	26,095.26	5,813.92	5.67	57.61	15.47	0.00	1,654.47	295.63	0.08	5,508.32	1,559.48	0.30	1.20
	Ss.	23.03	18,383.81	4,281.29	4.14	33.81	20.83	0.00	985.71	48.67	0.06	1,686.72	1,295.67	0.19	0.45
İvriz	Min.	41.73	4,948.06	3,048.83	1.61	108.88	62.71	0.01	614.12	353.71	0.06	2,029.81	847.05	0.24	0.41
	Max.	67.36	10,424.15	6,003.96	2.59	243.93	127.34	0.04	1,055.30	560.57	0.18	3,808.19	2,446.93	0.77	1.24
	Mean	60.24	7,513.43	4,492.35	2.17	156.16	92.07	0.02	751.54	444.85	0.11	2,835.04	1,733.05	0.40	0.85
	Ss.	7.66	1,627.92	996.69	0.35	41.37	18.02	0.01	137.32	53.12	0.04	572.93	480.61	0.16	0.26
Karaman	Min.	49.87	4,335.88	2,413.56	0.89	149.82	88.56	0.03	237.28	118.34	0.03	2,875.47	1,625.41	0.48	0.64
	Max.	59.11	6,998.69	3,550.53	1.80	259.71	143.01	0.05	2,217.39	1,154.10	0.40	5,494.82	2,846.17	1.18	1.42
	Mean	53.30	5,722.30	3,030.31	1.41	209.82	111.11	0.04	1,605.01	858.87	0.29	4,085.21	2,169.16	0.73	1.00
	Ss.	2.88	890.64	362.34	0.31	41.48	19.54	0.01	562.62	297.15	0.11	868.91	441.82	0.19	0.23
Ilgın	Min.	20.50	1,930.65	843.88	0.72	144.07	46.33	0.03	866.35	424.23	0.19	2,714.95	752.97	0.54	0.55
	Max.	60.57	6,466.30	2838.51	1.97	312.18	98.01	0.08	2,490.64	635.17	0.57	6,259.13	2,660.98	1.87	1.55
	Mean	42.79	4,163.60	1629.22	1.20	196.01	77.07	0.05	1,410.79	523.24	0.37	3,693.61	1,496.54	1.05	1.09
	Ss.	15.49	1,649.	657.72	0.45	52.86	17.01	0.01	566.86	59.13	0.13	1,083.95	530.61	0.51	0.28
Kıreli	Min.	9.95	3,095.44	611.64	0.43	199.62	24.24	0.03	2,640.16	497.61	0.61	5,154.36	512.93	0.70	0.75
	Max.	22.13	7,959.02	04,960.90	1.70	499.25	49.68	0.08	5,737.77	647.18	0.93	6,856.49	1,200.86	1.75	1.46
	Mean	15.11	5,311.94	731.92	1.04	279.41	39.41	0.06	4,108.97	572.33	0.80	5791.40	873.91	1.23	1.11
	Ss.	4.26	1,856.39	112.81	0.43	96.39	7.67	0.02	1,198.31	41.44	0.11	588.24	246.91	0.42	0.18

*A: Irrigation ratio (%); B: Annual irrigation water supplied per unit irrigated area (m^3 ha^{-1}); C: Annual irrigation water supplied per unit command area (m^3 ha^{-1}); D: Annual relative water supply; E: Total MOM cost per unit irrigated area (\$ ha^{-1}); F: Total MOM cost per unit command area (\$ ha^{-1}); G: Total MOM cost per unit irrigation water supplied to users (\$ m^{-3}); H: Total cost per unit irrigated area (\$ ha^{-1}); I: Total cost per unit command area (\$ ha^{-1}); J: Total cost per unit irrigation water supplied (\$ m^{-3}); K: Output per unit irrigated area (\$ ha^{-1}); L: Output per unit command area (\$ ha^{-1}); M: Output per unit irrigation water supplied to users (\$ m^{-3}); N: Output per unit irrigation water requirement (\$ m^{-3}).

Table 4. Principal component analysis conformity test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy		.581
Bartlett's Test of Sphericity	Approx. Chi-Square	1,080.642
	Df	91
	Sig.	.000*

*Significance level at $p < 0.01$

Differences between these indicators are higher in the first group, but lower in the third group. In short, values of the indicators in the third group are more similar to each other than that compared to the indicators in the first group. However, the primary aim of the principal component analysis was to use the coefficient as a parameter to calculate the quality index. In this case, it can be interpreted that the indicators in the first group are more effective in the ranking of irrigation schemes because they explain the variance better than the others (Table 5). On the other hand, the effects of indicators in the second and third groups had a lower effect on the ranking.

Table 5. Principal component matrix

Indicators*	Component		
	1	2	3
L	**-.867**	-.136	.250
A	**-.863**	-.133	-.313
H	**.833**	.035	.335
E	**.808**	-.157	-.046
J	**.737**	-.456	.359
C	**-.714**	.493	-.174
G	**.691**	-.477	.087
D	-.032	**.934**	.162
B	.040	**.923**	.170
M	.303	-.674	**.545**
N	.013	.052	**.908**
K	.302	.120	**.871**
F	-.012	-.117	-.309
I	-.038	-.221	.124

*A: Irrigation ratio (%); B: Annual irrigation water supplied per unit irrigated area (m^3 ha^{-1}); C: Annual irrigation water supplied per unit command area (m^3 ha^{-1}); D: Annual relative water supply; E: Total MOM cost per unit irrigated area (\$ ha^{-1}); F: Total MOM cost per unit command area (\$ ha^{-1}); G: Total MOM cost per unit irrigation water supplied to users (\$ m^{-3}); H: Total cost per unit irrigated area (\$ ha^{-1}); I: Total cost per unit command area (\$ ha^{-1}); J: Total cost per unit irrigation water supplied (\$ m^{-3}); K: Output per unit irrigated area (\$ ha^{-1}); L: Output per unit command area (\$ ha^{-1}); M: Output per unit irrigation water supplied to users (\$ m^{-3}); N: Output per unit irrigation water requirement (\$ m^{-3}).

Quality index

The success of ranking of the irrigation schemes resulting from the calculation of the quality index is given in Table 6. This ranking shows the most successful irrigation schemes by reducing all the performance indicators to a single number.

According to the quality index ranking, Ayrancı had the highest score and was the most successful irrigation scheme. However, this comparison only shows the rank among the irrigation schemes in the current study. Water was used more efficiently in Ayrancı while Kıreli irrigation scheme had ineffective water usage during the study period. The second most successful irrigation scheme was Çumra having 59,650 ha of command area. Ayrancı, Altınapa and Ilgın are small-scale irrigation schemes compared with the others and have less than 10,000 ha of command area. Thus, large scale irrigation schemes have more importance in the region. We observed that the last and the second last irrigation schemes, Kıreli with 10,511 ha and Karaman with 15,040 ha of command area, need more focus in terms of water management.

After identifying the strengths and weakness using direct methods such as external and internal (Değirmenci, 2001; Değirmenci et al., 2013; Arslan & Değirmenci, 2018), Çakmak et al. (2006) suggest that best management practices should be applied to irrigation schemes to achieve good water management in agriculture. Inefficient use of water is still one of the most important problems (Değirmenci et al., 2017) in the transferred irrigation schemes. These problems may be explained with some features of the irrigation schemes (Alcon et al., 2018; Zema et al., 2018a; Zema et al., 2018b).

Table 6. Quality index rank

Irrigation schemes	Quality index	Rank
Ayrancı	-62.7275	1
Çumra	-322.605	2
Altınapa	-370.725	3
İvriz	-458.451	4
Ilgın	-835.736	5
Karaman	-914.8	6
Kıreli	-1320.47	7

Particularly in central Anatolia, irrigation schemes have different types of features such as water diversion type, and the irrigation method used by farmers. Further studies should focus at determining more effective features in the region.

On the other hand, modernisation requirement may help increase performance of the irrigation schemes (Playán & Mateos, 2006; Renault, 1998). These modernisation processes should be continued to reach the goals with go gear technology considering energy requirement (Diaz et al., 2011; Lamaddalena & Khila, 2012).

CONCLUSIONS

Assessment of irrigation schemes with a large number of performance indicators make it cumbersome for evaluation and monitoring. In this respect, the principal component analysis and subsequent quality index can be used to evaluate these data without any issues. As a result of the analysis, the extent to which the indicator affects the irrigation schemes can easily be found. The quality index ranking showed that the Ayrancı scheme had the highest score and was the most successful irrigation scheme in the region but due to the small size of its command area, it had a relatively lower impact than the ones with higher impact. Thus Çumra, which had the biggest command area and is ranked at two, is important with respect to using irrigation water in the arid region. With the lowest score, Kıreli had the worst performance, and having more than 10,000 ha of command area, contributed to its lower score. Despite the higher agricultural production, the larger financial indicator values placed Kıreli irrigation scheme in the lowest rank. This shows that water usage is the most important factor in the central Anatolia region, indicating that further research should focus on improvising the water use efficiency. Based on principal component analysis, and general statistics, the average amount of irrigation water supplied to users per unit irrigated area is approximately 9000 m^3 ha^{-1} annually, a figure which is very high for an arid region. Thus, the problems that prevent effective use of irrigation water should be eliminated.

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