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Forecasting future performance of irrigation schemes: The case of Bergama

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ABSTRACT

Potential outputs of irrigation should be put forth to improve the yields in agricultural practices. Available water resources should efficiently be used to improve yields and inputs should be minimized. Performance assessment of irrigation schemes is an importance issue for improved yields and to take relevant measured. Statistical methods are used for performance assessment of irrigation schemes with the use of various indicators. Forecasts for future performance of irrigation shames will facilitate the steps to be taken by decision-makers to improve performance. In this study, time series – ARIMA method was used to forecast future performance of Bergama irrigation scheme for 2017-2021 period. The indicator values of annual irrigation water supply per unit command area, output per unit command area and total expenditure per unit command area for 2006-2017 period were used to estimate performance indicators for 2017-2021 period. In 2021, at 95% probability, the lowest annual irrigation water supply per unit-command area was calculated as 4365.10 m^3 ha^{-1} and the highest as 16835.69 m^3 ha^{-1}; the lowest output per unit command area was calculated as -5076.10 € ha^{-1} and the highest as 10401.2 € ha^{-1}; the lowest total expenditure per unit command area was calculated as -2200.41 € ha^{-1} and the highest as 1866.31 € ha^{-1}. Present forecasts of time series -ARIMA method with the use of data of 2006-2016 period revealed that annual irrigation water supply per unit-command area and output per unit command area will increase and total expenditure per unit command area will decrease in years.

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Introduction

Water is an essential component of life on earth and water resources are continuously depleting with increasing world population. Global warming and climate change further aggravate the water-related problems. Then, efficient and sustainable use of vital resources have become critical issues in world agenda. Food supply of increasing populations have also become a challenging issue. Meeting requirement food demands will be possible only with maximum or optimum use of available resources in agriculture.

Water is the primary input in agriculture. Current research mostly focuses on efficient use of water resources. In Turkey, annual water consumption of different sectors reached to 57 billion m^3 (DSI, 2019). Of such a quantity, about 44,0 billion m^3 (77%) are used in irrigation, about 13 billion m^3 (26%) are used for domestic and industry (DSI, 2019). According to National Water Plan 2019-2023, migrations from rural parts to urban sections and rapidly increasing populations increased demands for agriculture, already using 74% of available water resources of Turkey. Together with accelerated developments achieved in industry, industrial water use reached to 13% level and in 13% in domestic use (Anonymous, 2020; DSI, 2019). Such a high level of water uses in industry exerted a pressure on agricultural sector in terms of quality, rather than quantity of water.

Turkey has 25 river basins and monitoring programs have been prepared in accordance with EU norms. Watershed Management Plans are being prepared and targeted to be completed by the year 2023. An efficient supply-and-demand balance is totally dependent on proper identification of intersectoral water use demands. In Turkey, during the last 20 years, a 40% increase was seen in total water consumption. Considering the population growth rate and growth of agricultural, domestic, industrial and energy sectors, it was projected that amount of water needed within the next 25 years will triple the present water consumption. Such increasing demands will further increase the pressure exerted on water resources. By the year 2030, Turkey planned to use 112 billion m^3 of available water resources and allocate 64% of this source to agriculture, 20% to industrial uses and 16% to domestic uses (Şura, 2017). Considering the current use in agriculture (74%), it was thought that water use performance in agriculture should be well-assessed and planed accordingly. By the year 2017, total size of lands opened for irrigation reached to 6,5 million hectares constituting about 72% of economically irrigable lands of Turkey. In 2016, net irrigation area was 3 million hectares (DSI, 2019). Majority of irrigable lands (75-80%) is irrigated with surface waters and the rest is irrigated with groundwater. In 2016, 43 billion m^3 water was used in irrigation and 77% of this water was supplied from surface water and 23% from groundwater (State Hydraulic Works, 2017). Leakage and evaporative losses are generally encountered in traditional systems. Through transition from traditional systems into modern systems, serious effort has been spent to improve irrigation efficiency, but overall efficiency is still around 51% level. National Water Plan 2019-2023 (2019) targets to increase efficiency to 55% level by the year 2024.

Several studies have been conducted worldwide about water use. McGlade et al. (2012) and Millennium Ecosystem Assessment (MEA, 2005) indicated that water was perceived as a renewable but limited resource in several countries and regions and excessive use of available water resources will aggravate water stress and exert serious threats on ecosystems and biodiversity. Shiklomanov and Rodda (2003) indicated agricultural irrigations, constituting about 86% of annual global water consumption, as the most significant factor for water consumption. Limited nature of water and ever-increasing water demands have made water use and management even more the significant issues. Several studies indicated that relevant measures should be taken to improve efficiency in water use and management, otherwise mankind will encounter several water-related problems (Alcamo et al. 1997; Seckler et al. 1998; Falkenmark and Rockström, 2004). There are several studies conducted on agricultural water use and management. Various indicators were developed to assess the performance of irrigation schemes (Molden et al., 1998; Malano and Burton, 2001; Burt, 2001; Renault et al., 2007). Several studies were also conducted with the use of these indicators (Çakmak 2001; Değirmenci, 2004; Rodriguez-Diaz et al., 2008; Corcoles et al., 2010; Alcon et al., 2017; Zema et al., 2018; Arslan and Değirmenci, 2018; Kartal et al., 2019; Kartal et al., 2020). Majority of these studies conducted to assess and compare the performance of irrigation organizations. In this study, current data of Bergama irrigation scheme located in İzmir province of Turkey were used to calculate future performance of the irrigation scheme with the use of performance indicators. Recommendations were provided to improve estimated future performance of the irrigation scheme.

Material and Method

The data supplied from General Directorate of State Hydraulic Works (DSI) for Bergama irrigation scheme for the years 2006-2019 period were used as the primary material of the present study. Data was obtained from DSI annual reports (DSI, 2019). Bergama irrigation scheme has an irrigation area of 3716 ha and uses gravity irrigation. The irrigation scheme has a total canal length of 25,9 km, of which 20 km is lined-canal and 5,9 km is canalette. Irrigation water is supplied from Kestel and Bergama rivers. About 5% of irrigations are performed with classical system and 95% are performed with canalette system. About 2892 ha (78%) of irrigation area is actively irrigated. Changing with the years, respectively maize, cotton and vegetables are mostly grown in irrigation district.

Method

Data of 2006-2016 period of Bergama irrigation scheme were used to make estimations for 2017-2021 period. Annual irrigation water supply per unit command area, total expenditure per unit command area and output per unit command area were used as performance indicators. Equations provided in Table 1 were used to calculate the performance indicators used to determine the performance of Bergama irrigation scheme (Bos et al., 1994; Molden et al., 1998; Malano and Burton, 2001; Burt, 2001; Renault et al., 2007).

Data Analysis

Data of 2006-2016 period were used in time series analysis to estimate the performance for 2017-2021 period. ARIMA is the strongest model used in future estimations with time series analysis (Box et al., 1994). The method is composed of model definition, parameter estimation and identification model validity phases. ARIMA compares different models while identifying the best model for relevant data (Nelson, 1991; Engle, 1982; Campbell and Diebold, 2005). Comparisons reveal the best ARIMA (p, d, q) arrangement and offers fit indices. Potential models are compared with the use of ARIMA and then a decision is made about which model was more appropriate for relevant data and forecasting. Assessments are made based on Bayes Information Criteria (BIC) and some goodness-of-fit statistics (Neath and Cavanaugh, 2017).

Table 1. Performance indicators used in calculations and calculation methods

Indicators	Definition
Annual irrigation water supply per unitcommand area (m^3 ha^{-1})	$\frac{\text{Total annual volume of irrigation supply}}{\text{Total annual irrigated area}}$
Total expenditure per unit command area (€ ha^{-1})	$\frac{\text{Total expenditure}}{\text{Command area}}$
Output per unit command area (€ ha^{-1})	$\frac{\text{Total annual value of agricultural production}}{\text{Command area}}$

Table 2. Codes used for analysis

```
### The code used to download the used package ###
>install.packages("forecast")
>library(forecast)
### code used in time series generation###
>Y<-ts(data$variable, start = c(year,1), f=1)
### Code used for modeling with ARIMA###
>fitarima<-auto.arima(Y, stepwise=F, approximation = F, trace = T, seasonal = F)
###code used for estimation###
>fc<- forecast(fitarima, h=5
###The code used to draw the forecast chart###
>plot(fc, main="…", ylab="…", xlab="…")
### The code that prints out the modeling made with ARIMA###
>print(summary(fitarima))
### the code used to print the estimated values ###
>print(summary(fc))
```

While deciding about which ARIMA model is more suitable, BIC, Root Mean Square Error of Approximation (RMSE), Mean Absolute Percentage Error (MAPE), Mean Absolute Error (MAE) and Logistic Likelihood (LL) values were used. Parameters, in other words forecasts, are obtained through maximum likelihood asymptotically true for time series (Mandal, 2005). In present study, "forecast" package of R software was used in formation of time series, parameter estimations and forecasts. Analyses were conducted with the following code are given in Table 2.

Results

In this chapter, model information about performance indicators, fit indices and estimation results were presented.

For Bergama irrigation scheme data, ARIMA (0,1,0) model was selected for annual irrigation water supply per unit command area; (0,1,0) was selected for output per unit command area and (0,1,0) was selected for total expenditure per unit command area. The forecasts made for 2017-2021 period with the use of specified ARIMA models were provided below respectively for annual irrigation water supply per unit command area, output per unit command area and total expenditure per unit command area.

Variations and estimations of annual irrigation water supply per unit command area are presented in Figure 1. Forecast upper limits for the years 2017-2021 increased gradually within the years. Therefore, it could be stated that total annual irrigation water supply per unit command area will increase gradually. Estimations for the years 2017-2021 are provided in Table 3.

As can be seen in Table 4, at 80% probability, annual irrigation water supply per unit command area was estimated to be between 5923.30 - 11500.32 m^3 ha^{-1} in 2017 and between 1755.15 - 14225.74 m^3 ha^{-1} in 2021. At 95% probability, the lowest value was estimated as 7090.51 m^3 ha^{-1} and the greatest as 12667.53 m^3 ha^{-1} in 2017; the lowest value was estimated as 4365.10 m^3 ha^{-1} and the greatest as 16835.69 m^3 ha^{-1} in 2021. It was observed that annual irrigation water supply per unit command area increased within the years (Figure 1).

Forecasts for output per unit command area are presented in Figure 2. An increase was foreseen in this performance indicator within years. Estimated values are provided in Table 5.

As can be seen in Table 5, at 80% probability, the lowest output per unit command area was calculated as 399.63 € ha^{-1} and the greatest as 4925.46 € ha^{-1} in 2017; the lowest value was calculated as -2397.48 € ha^{-1} and the greatest as 7722.58 € ha^{-1} in 2021. At 95% probability, the lowest output per unit command area was calculated as -798.28 € ha^{-1} and the greatest as 6123.38 € ha^{-1} in 2017; the lowest value was calculated as -2397.48 € ha^{-1} and the greatest as 7722.58 € ha^{-1} in 2021. The lower limits at 80 and 95% probability had negative values. Statistically, time series analysis may reveal negative values, but output per unit command area will not have a negative value in practice. Therefore, negative values were accepted as 0 € ha^{-1} for output per unit command area. Output per unit command area values increased with years and such changes are presented in Figure 2.

Table 3. Fit indexes of ARIMA models

Performance indicators	Fit Statistics					Model
	RMSE	MAPE	MAE	Normalized BIC	LL	
Annual irrigation water delivery per unit command area	1640.42	20.90	1277.86	179.69	88.69	ARIMA(0,1,0)
Output per unit command area	1683.58	24.08	1276.63	180.21	88.95	ARIMA(0,1,0)
Total expenditure per unit command area	126.53	11.14	100.77	116.67	57.24	ARIMA(0,2,0)

Table 4. Annual irrigation water delivery per unit command area estimates

Years	Lower (%95)	Lower (%80)	Forecast	Upper (%80)	Upper (%95)
2017	7090.51	5923.30	9295.42	11500.32	12667.53
2018	6177.21	4526.53	9295.42	12413.63	14064.31
2019	5476.41	3454.75	9295.42	13114.43	15136.09
2020	4885.61	2551.19	9295.42	13705.23	16039.64
2021	4365.10	1755.15	9295.42	14225.74	16835.69

Table 5. Output per unit command area estimates

Years	Lower (%80)	Lower (%95)	Forecast	Upper (%95)	Upper (%80)
2017	399.63	-798.28	2662.55	6123.38	4925.46
2018	-537.69	-2231.80	2662.55	7556.90	5862.79
2019	-1256.93	-3331.78	2662.55	8656.88	6582.03
2020	-1863.28	-4259.11	2662.55	9584.21	7188.38
2021	-2397.48	-5076.10	2662.55	10401.2	7722.58

Table 6. Total expenditure per unit command area estimates

Years	Lower (%80)	Lower (%95)	Forecast	Upper (%95)	Upper (%80)
2017	380.11	285.21	559.39	833.56	738.66
2018	-23.09	-235.30	377.78	990.86	778.65
2019	-474.61	-829.71	196.17	1222.05	866.95
2020	-967.37	-1487.17	14.56	1516.29	996.49
2021	-1496.59	-2200.41	-167.05	1866.31	1162.49

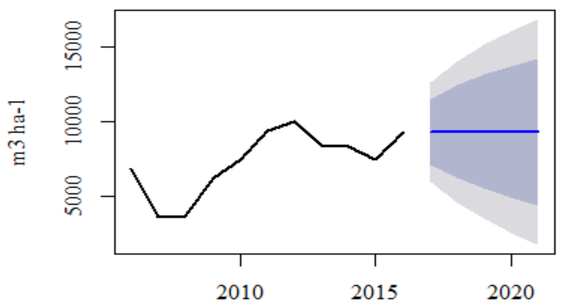

Figure 1. Annual irrigation water delivery per unit command area

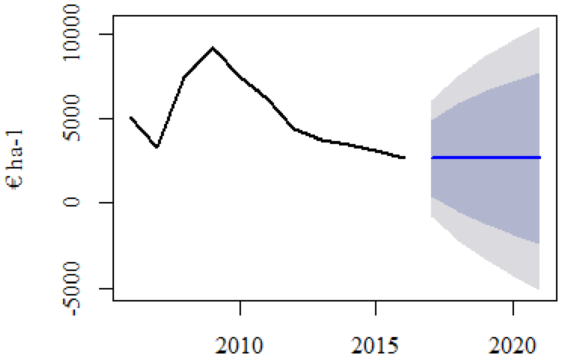

Figure 2. Output per unit command area

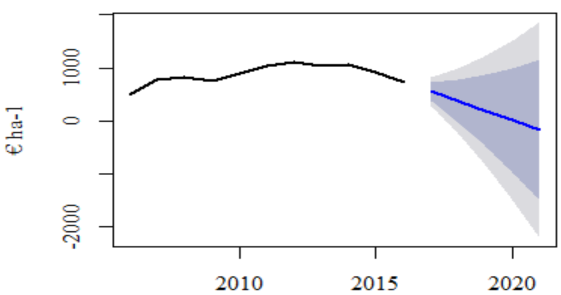

Figure 3. Total expenditure per unit command area

The data about total expenditure per unit command area until the year 2016 and estimated values for 2017 - 2021 period are presented in Figure 3. Total expenditure per unit command area decreased with the years. Estimated values are provided in Table 6.

As can be seen in Table 4, at 80% probability, the lowest total expenditure per unit command area was calculated as 380.11 € ha^{-1} and the greatest as 738.66 € ha^{-1} in 2017; the lowest value was calculated as -1496.59 € ha^{-1} and the greatest as 1162.49 € ha^{-1} in 2021. At 95% probability, the lowest total expenditure per unit command area was calculated as 285.21 € ha^{-1} and the greatest as 833.56 € ha^{-1} in 2017; the lowest value was calculated as -2200.41 € ha^{-1} and the greatest as 1866.31 € ha^{-1} in 2021. As can be inferred from Figure 3, total expenditure per unit command area will decrease in years.

ARIMA model couldn't catch a trend in the indicators that annual irrigation water delivery per unit command area estimates. Therefore, forecast values are assumed same for the predicted years, however, vice versa for the indicator total expenditure per unit command area estimates. But, still upper and lower values of the indicators gives the range for the predicted years.

Discussion, Conclusion and Recommendations

Time series analysis with ARIMA model in agricultural studies, especially irrigation sector, are getting widely used to predict some values such as performance indicators (Arslan, 2020), irrigation management (Aljoumani et al., 2012), tank irrigation (Narayanamoorthy, 2007). The drought regions (Pamuk et al., 2004) show low performance in terms of irrigation ratio, indicates irrigated area over command area, due to lack of irrigation water (DSI, 2019). Water is the most important input in agriculture and its users are water user associations (WUA), so prediction of the performance of them is of great importance (Arslan, 2020).

The study support that time Series analysis is among the strongest tools used in forecasting future performance of irrigation schemes. Time Series – ARIMA method was used in present study to calculate future performance of Bergama irrigation scheme. With the use of ARIMA method, performance data of previous years were used and future performance of the irrigation scheme was forecasted. In this sense, annual irrigation water supply per unit command area, total expenditure per unit command area and output per unit command area of Bergama irrigation scheme for 2006-2016 period were used and forecasts were made for 2017-2021 period. Present findings revealed that there would be increases in upper limits of annual irrigation water supply per unit-command area and output per unit command area indicators and decreases in total expenditure per unit command area indicator in years. For Bergama irrigation scheme, annual irrigation water supply per unit-command area and output per unit command area were not consistent in 2006-2016 period. In other words, there was not a systematic increase or decrease in these parameters in years. Increases in some years were followed by a serious decline. Therefore, it was not possible to get point estimations for these parameters. Then, the lowest and the greatest possible values were calculated for these parameters. As compared to aforementioned two parameters, total expenditure per unit command area indicator was more consistent in 2006-2016 period. Analysis results revealed that such a case could also be reflecting in upcoming years. Therefore, it was forecasted that total expenditure per unit command area will continue to decrease in years. It was though that upper and lower limits calculated for three performance indicators would provide significant data for decision-makers to improve future performance of irrigation schemes. In line with present findings, relevant improvements and implementations should be put in practice.

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