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Research Article

Use of Remote Sensing and Geographic Information Systems in Irrigation Performance: A Case Study of Atabey Irrigation Scheme

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Abstract

In this study, the irrigation performance of Atabey Irrigation Scheme was assessed by making use of Remote Sensing (RS) and the Geographic Information System (GIS). For this purpose, the crop pattern maps of the scheme were generated by the help of the supervised classification method with the RapidEye satellite data of 2012 concerning the study area by employing the RS techniques, whereas the canal maps of the scheme were generated by the help of the techniques of the Geographic Information System. By the help of these data, the monthly water supply ratios – one of the performance indicators – were computed. A total of 24 crop classes, 10 of which were in the irrigated area corresponding to about one-third (5,239.75 ha; 33.72%) of the total area but the remaining 14 of which were in the non-irrigated (rainfed agriculture) area corresponding to about two-thirds (10,299.74 ha; 66.28%) of the scheme area, were determined as a result of the crop pattern classification. The total irrigation water requirement for Atabey irrigation scheme was calculated as 42,618 m^3 minimum and 5,647,246 m^3 at the maximum between April and October. The Relative Water Supply (RWS) in the months concerned ranged from 28.16 to 2.39 and the average in 2012 was calculated as 3.25. The assessment, collection, operating and maintenance expenses of the scheme and, by the help of these data, its fee collection and financial efficiency ratios were calculated. The fee collection ratio was found as 88.12% and the financial efficiency ratio as 1.42 at the scheme in 2012.

Key words: Remote sensing, geographic information systems, irrigation performance, relative water supply.

Sulama Performansının Belirlenmesinde Uzaktan Algılama ve Coğrafi Bilgi Sistemlerinin Kullanımı: Atabey Sulama Şebekesi Örneği

Özet

Bu çalışmada; Atabey Sulama Şebekesinin Uzaktan Algılama ve Coğrafi Bilgi Sistemi'nden yararlanılarak sulama performansı değerlendirilmiştir. Bu amaçla, Uzaktan Algılama teknikleri kullanılarak çalışma alanına ilişkin 2012 yılı RapidEye uydu verisi ile kontrollü (supervised) sınıflandırma yöntemi yardımıyla şebekeye ait bitki deseni haritaları, Coğrafi Bilgi Sistemi teknikleri yardımıyla da şebekeye ilişkin, kanal haritaları oluşturulmuştur. Bu veriler yardımı ile performans göstergelerinden biri olan aylık su temini oranları hesaplanmıştır. Bitki deseni sınıflandırması sonucunda 10 tanesi toplam alanın yaklaşık 1/3'üne karşılık gelen (5239.75 ha; %33.72) sulanan alanda, geriye kalan 14 tanesi ise şebeke alanının yaklaşık 2/3'üne denk gelen (10299.74 ha; % 66.28) sulanmayan (kuru tarım) alanda yer alan toplam 24 bitki sınıfı belirlenmiştir. Atabey sulama şebekesi için toplam sulama suyu ihtiyacı nisan-ekim ayları arasında en az 42618 m^3 ile en fazla 5647246 m3 olarak hesaplanmıştır. Belirtilen aylardaki su temini oranı ise 28.16-2.39 arasında değişmiş, 2012 yılında ortalama su temini oranı ise 3.25 olarak hesaplanmıştır. Şebekenin tahakkuk, tahsilat, işletme ve bakım masrafları ile bu veriler yardımıyla tahsilat oranı ve mali yeterlilik oranları hesaplanmıştır. Şebekede 2012 yılında tahsilat oranı %88.12, mali yeterlilik oranı ise 1.42 olarak bulunmuştur.

Anahtar kelimeler: Uzaktan algılama, coğrafi bilgi sistemleri, sulama performansı, su sağlama oranı.

Introduction

The rapidly increasing world population makes the optimum utilization of natural resources inevitable. The requirement for water at every moment, and in every sphere, of life envisages an efficient distribution of water among different spheres of use to ensure the maximum utilization of water resources (Karataş, 2006). It is quite important to decide how water – which has become a rapidly decreasing resource – will be used more efficiently, equally, and sustainably. Ensuring continuity in the use of resources by determining the efficiency of land and water resources and finding out the reasons for low and high efficiency are the focal points of the increasing irrigation performance studies. Therefore, it has in a sense become inevitable to convey the irrigation water to be used in crop cultivation to the irrigation areas with the minimum loss within possibilities, to distribute it within the area, and to apply it to the plant root zone in such a way that will meet the plant water requirement at the desired level. These operations, which are required for the efficient use of water, should be carried out and the data to be obtained from the irrigation scheme should be obtained and processed quickly and reliably and turned into a form that the decision-makers can use. About 70% of the water annually used in Turkey, as in the world, is used in agricultural irrigation. Thus, the efficient use of the water allocated for agriculture and the opening of new areas for irrigation with the saved water or its use in other sectors are gradually gaining importance, also given the increasing world population, the contamination of water resources, and the unbalanced distribution of rainfall in the recent years. The technologies which will provide the efficient use of water resources such as remote sensing and geographic information systems should be adapted to the irrigation schemes which cover large areas and therefore use considerable water (Uçar and Başayiğit, 2001). In agriculture, remote sensing technologies are employed in such fields as crop production forecasting, assessment of crop damage and crop progress, identification of planting and harvesting dates, crop yield modelling, soil moisture estimation, soil mapping, monitoring of droughts, and climate change monitoring (Sharma et al., 2018). In irrigated agriculture, however, they are used in the studies of daily or seasonal evapotranspiration, crop stress, irrigation monitoring and management, determination of the water content of field crops, water resources mapping, and salinity. By using these systems, the performances of irrigation schemes were determined in India by Thiruvengadachari and Sakthivadivel (1997), in Brazil by Bastieansen et al. (2000), in Niger by Zwart et al. (2010), in Córdoba, Spain by Santos et al. (2010), in Egypt by Elnmer et al. (2018), in California by Taghvaeian et al. (2018), and in Swaziland by Karimi et al. (2019).

In this study, a database of Atabey irrigation scheme was generated by employing the technologies of remote sensing and geographic information systems. The performance evaluation of Atabey irrigation scheme was done with this database. It is thought that irrigation scheme managers and decision-makers will have the ability of faster and more accurate decision-making thanks to this database.

Materials and Methods

Located 15 km to the north of Isparta province at the District of Lakes, the study area lies between the altitudes of 850 and 1,000 m. Selected as the study area, Atabey irrigation scheme covers some gross agricultural land of 16,471 ha and some net agricultural land of 14,000 ha encompassing the lands of Atabey and Gönen districts as well as of the 11 settlement units affiliated to them (Figure 1). The study area, a transitional zone between the Central Anatolia Region and the Mediterranean Region, reflects the characteristics of both climates. Its annual mean temperature is 12.2^{o}C. The coldest month (1.9^{o}C) is January, whereas the hottest month (23.6^{o}C) is July. The annual mean precipitation is 537.3 mm and the mean relative humidity is 66.7%. Precipitation was measured as 107.4 mm in May but as 205.1 mm in October in 2012, when the research was carried out. The facility was put into operation in 1974 and its water resource is Lake Eğirdir.

The methodology applied in the study includes the stages of (1) generating the digital data layers; (2) fieldwork; (3) generating the crop pattern maps; (4) calculating evapotranspiration; and (5) performance assessment. ArcGis 9.1 geographic information systems (GIS) software and Erdas Imagine 9.1 remote sensing software were used to generate the digital database.

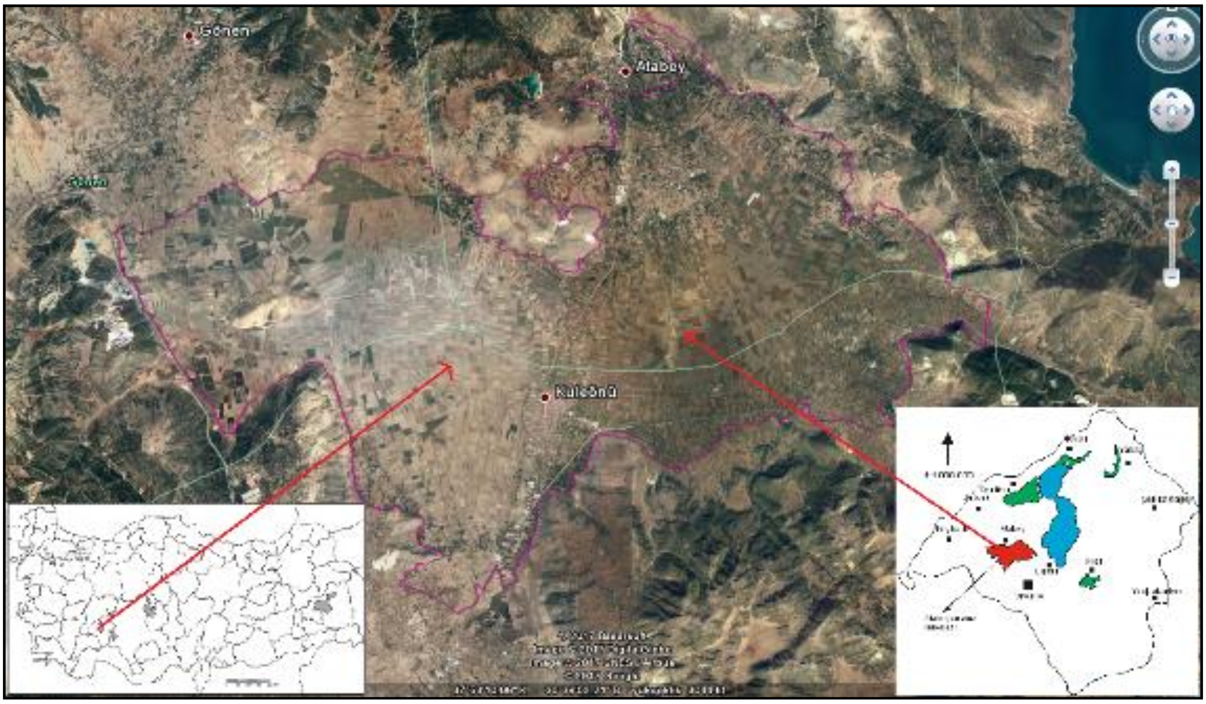

Figure 1. The Google Earth image of the study area (Anonymous, 2017a).

Determination of the crop pattern

The data by the Farmer Registration System of the Provincial Directorate for Food, Agriculture, and Livestock in Isparta and the data by Atabey Irrigation Association were evaluated at the first stage of the classification. As a result of this evaluation, it was seen that rainfed and irrigated agricultural lands were available within the irrigation scheme and the species on these lands were determined. Before making the image classification, which was the second stage, comments on the image were made by using 5 (NIR), 3 (red), and 1 (blue) band combination in the satellite data. At the third stage, the approximate classification of the crop pattern was made by using these comments. The RapidEye satellite data were utilized and the supervised classification method was employed when determining the crop pattern. Land supervisions were carried out to combine the classes in the irrigated areas of priority for the study out of the classes (85 classes) resulting from the classification and to distinguish the confused classes.

Calculation of evapotranspiration

Cropwat 8.0 computer software, which calculated according to the Penman-Monteith method, was used to calculate the evapotranspiration values of the crops found in the crop pattern determined in the study area. The climatic data by the Directorate for Meteorology in Isparta, obtained from the Directorate General for Meteorology, were used to compute evapotranspiration.

Performance assessment

Relative water supply, fee collection ratio and financial efficiency ratio were used in the performance assessment of the study area. The water supply amounts were obtained from the records of the 18th Regional Directorate of the State Hydraulic Works and of Atabey Irrigation Association. The water demand of the scheme was calculated by relating the evapotranspiration values computed with the Cropwat method according to the Penman-Monteith method. The irrigation water fee assessment and fee collection amounts were obtained from the records of Atabey Irrigation Scheme Association. RWS, fee collection ratio and financial efficiency ratio by month in the irrigation season were calculated by means of the following equations.

(1) Relative Water Supply (RWS) = Amount of water delivered to the scheme/Water demand of the scheme;

(2) Fee Collection Ratio (FCR) = Fee Collection/Assessment;

(3) Financial Efficiency Ratio (FER) = Assessment/Operating and maintenance expenses.

Results and Discussions

A canal map of Atabey irrigation scheme

Irrigation water for Atabey irrigation scheme is obtained from Lake Eğirdir by means of Bedre pump station. There are two main canals at the scheme. The capacity of the right main canal is 3.5 $m^3 h^{-1}$, whereas the capacity of the left main canal is 2.57 $m^3 h^{-1}$. While the right and left main canals at the scheme are generally trapezoid-sectioned, the secondary and tertiary canals are in the form of flumes. The total length of the main canal including both right and left main canals is 43,742 m (Figure 2). The overlaid existing crop pattern on the canal map is seen in Figure 3. As it will also be seen from this map, there are hardly any irrigated areas in the places with no canal scheme. On the other hand, producers irrigate with the water they obtain from the wells they dug with their own possibilities in those places on the map which are classified as irrigated lands with no canals. The canals in these regions were removed as they did not suit the block planning of the existing canals in the land consolidation projects implemented in Bozanönü and Kuleönü. There is a decrease in the intensity of canals since the canal scheme planned to be built within land consolidation was not built for various reasons. This leads to the occurrence of those areas which cannot be irrigated although they are indeed within the irrigation scheme (Figure 3).

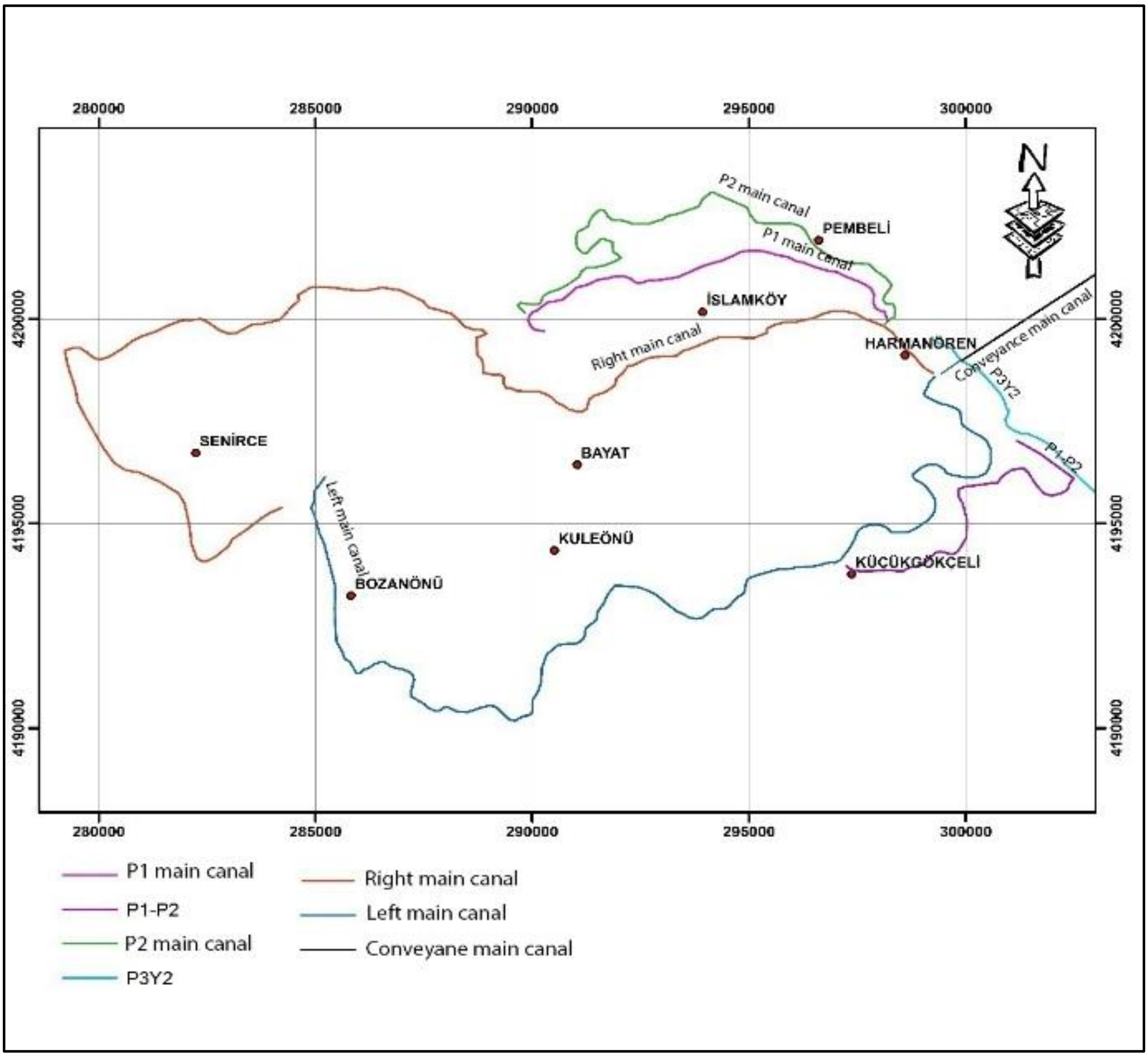

Figure 2. A view of the main canals at Atabey irrigation scheme.

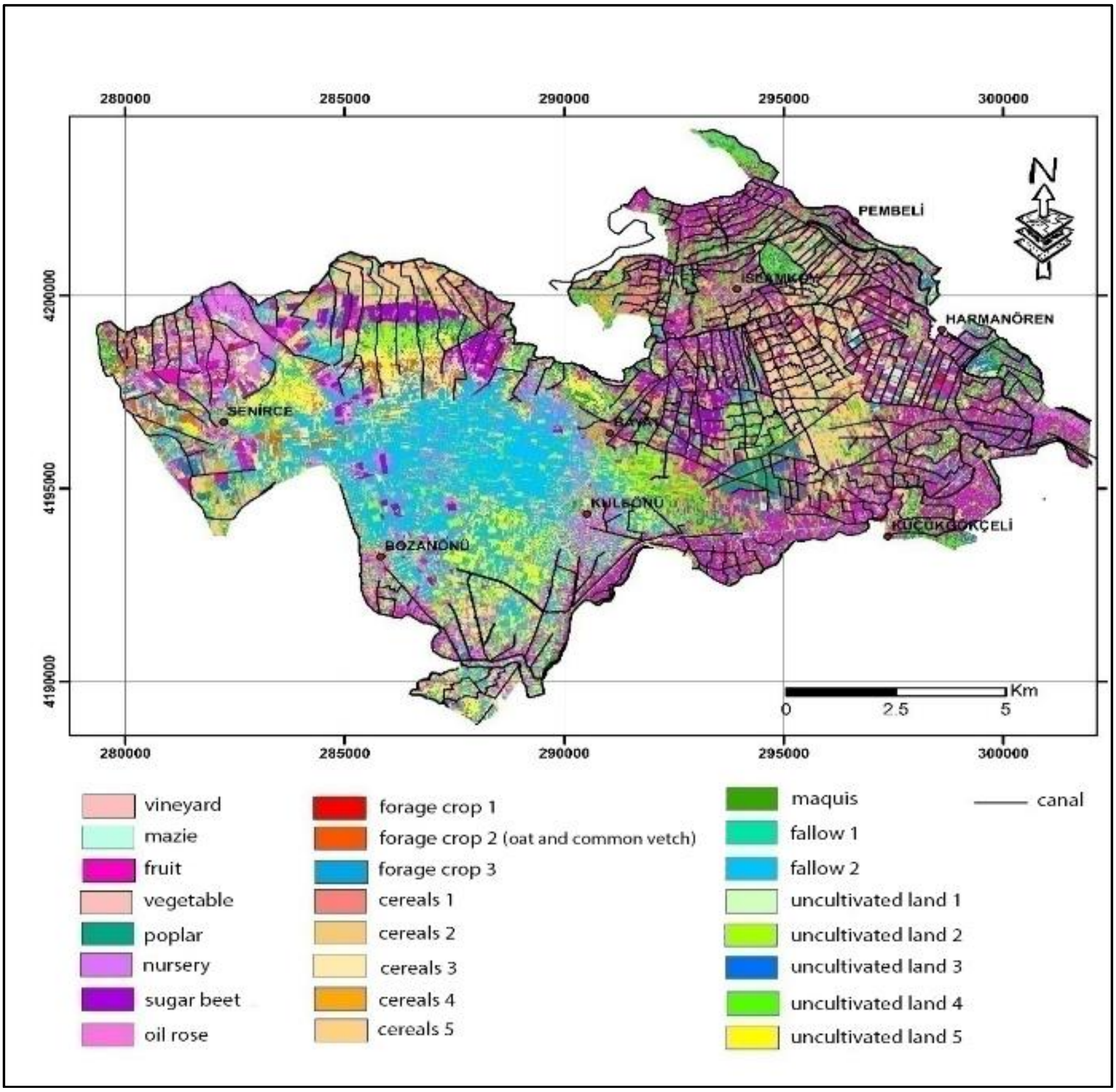

Figure 3. A map of the existing crop pattern and canals.

Classification of the crop pattern

The crop classes obtained with the supervised classification performed by using the RapidEye satellite data about Atabey Irrigation Scheme – the study area – in the study are provided in Figure 4. A total of 24 different crop classes were determined as a result of the classification. Of the crop classes determined, 10 are the crop classes in the area where irrigated agriculture is performed, but 14 represent the crop classes in the areas where rainfed agriculture is carried out within Atabey irrigation scheme (Figure 5). The crop classes obtained as a result of the classification performed in the irrigated agricultural lands are presented in Table 1. As seen in the table, 10 classes, namely vineyard (1.89%), vegetable (0.92%), poplar (2.48%), maize (3.12%), fruit (48.91%), nursery (11.42%), forage crop 1 (1.36%), forage crop 3 (5.30%), flower garden (11.85%), and sugar beet (12.75%), were determined in the irrigated area within the scheme. Differences in the reflection of the forage crop were observed for such reasons as the differences in soil properties, variety of the forage crop, and sowing time. By making use of these reflection values and the results of field observations, the forage crop areas were divided into 2 classes in the region where irrigated agriculture was performed. When the fruit and sapling growing areas are considered together, it is seen that fruit growing is performed in about 60.33% of the irrigated area, followed by sugar beet (12.75%) and oil rose (11.85%). The irrigated area within the scheme (5,239.75 ha) makes up about one-third of the total areas.

A map of the crop pattern in the non-irrigated (rainfed agriculture) areas within the scheme is presented in Figure 6. At the end of the supervised classification performed, it was discovered that the area of 10,299.74 ha corresponding to 66.28% of the total areas of the scheme was not irrigated. At the end of the supervised classification, a total of 14 crop classes were determined in the non-irrigated areas. According to the real location data obtained at the end of the land supervisions, map supervisions, and field interviews for these classes, it was established that there were 5 different crop patterns in the non-irrigated area (Table 2).

Table 1. The crop pattern in the area where irrigated agriculture was performed within the scheme

Crop classes	Area (ha)	Total areas (%)	Irrigated area (%)
Vineyard	99.01	0.64	1.89
Vegetable	48.26	0.31	0.92
Poplar	129.73	0.83	2.48
Maize	163.30	1.05	3.12
Fruit	2562.97	16.49	48.91
Nursery	598.39	3.85	11.42
Forage crop1	71.39	0.46	1.36
Forage crop3	277.64	1.79	5.30
Oil rose	620.90	4.00	11.85
Sugar beet	668.17	4.30	12.75
Total	5239.75	33.72	100.00

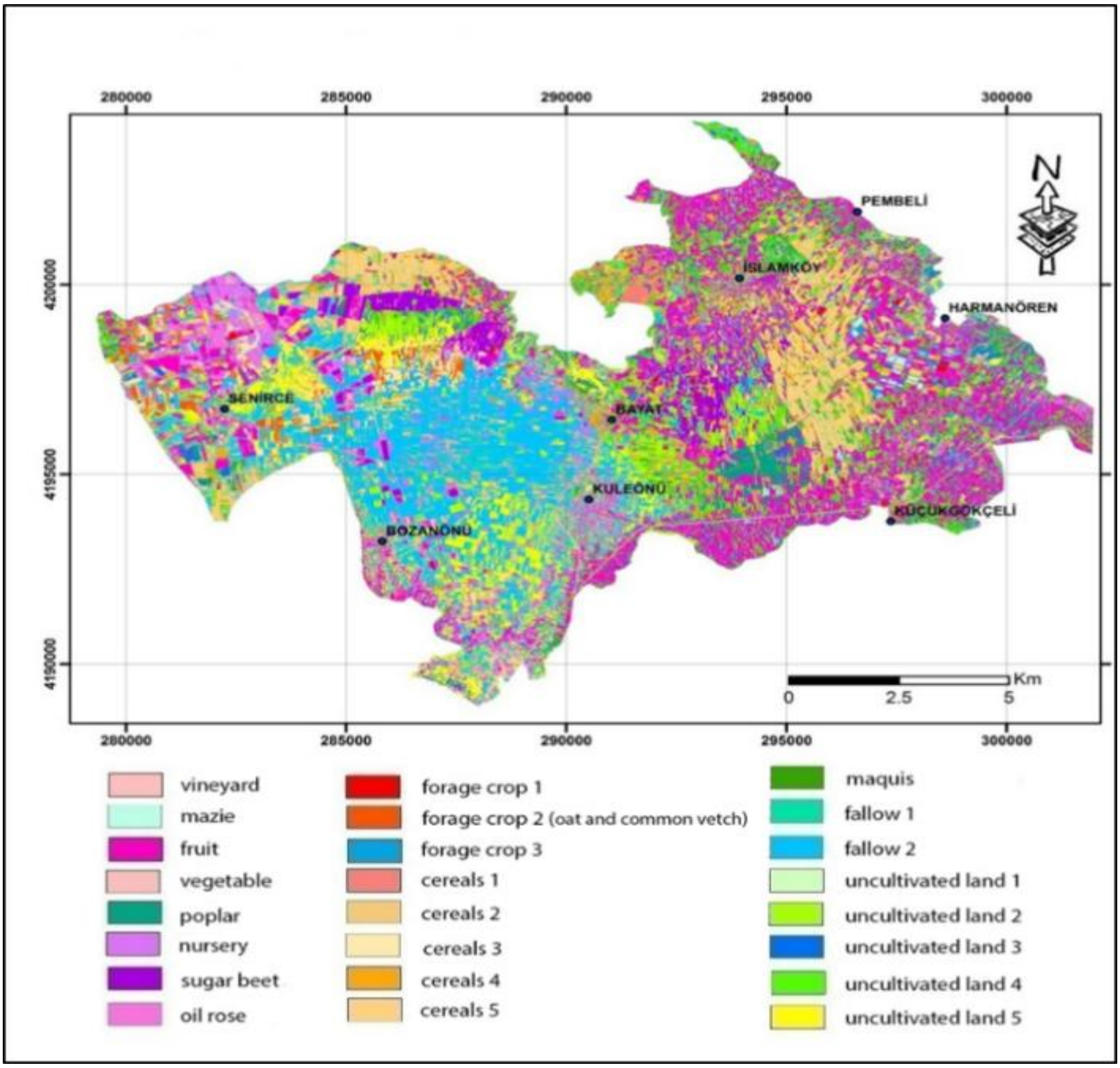

Figure 4. A map of the crop pattern obtained with supervised classification.

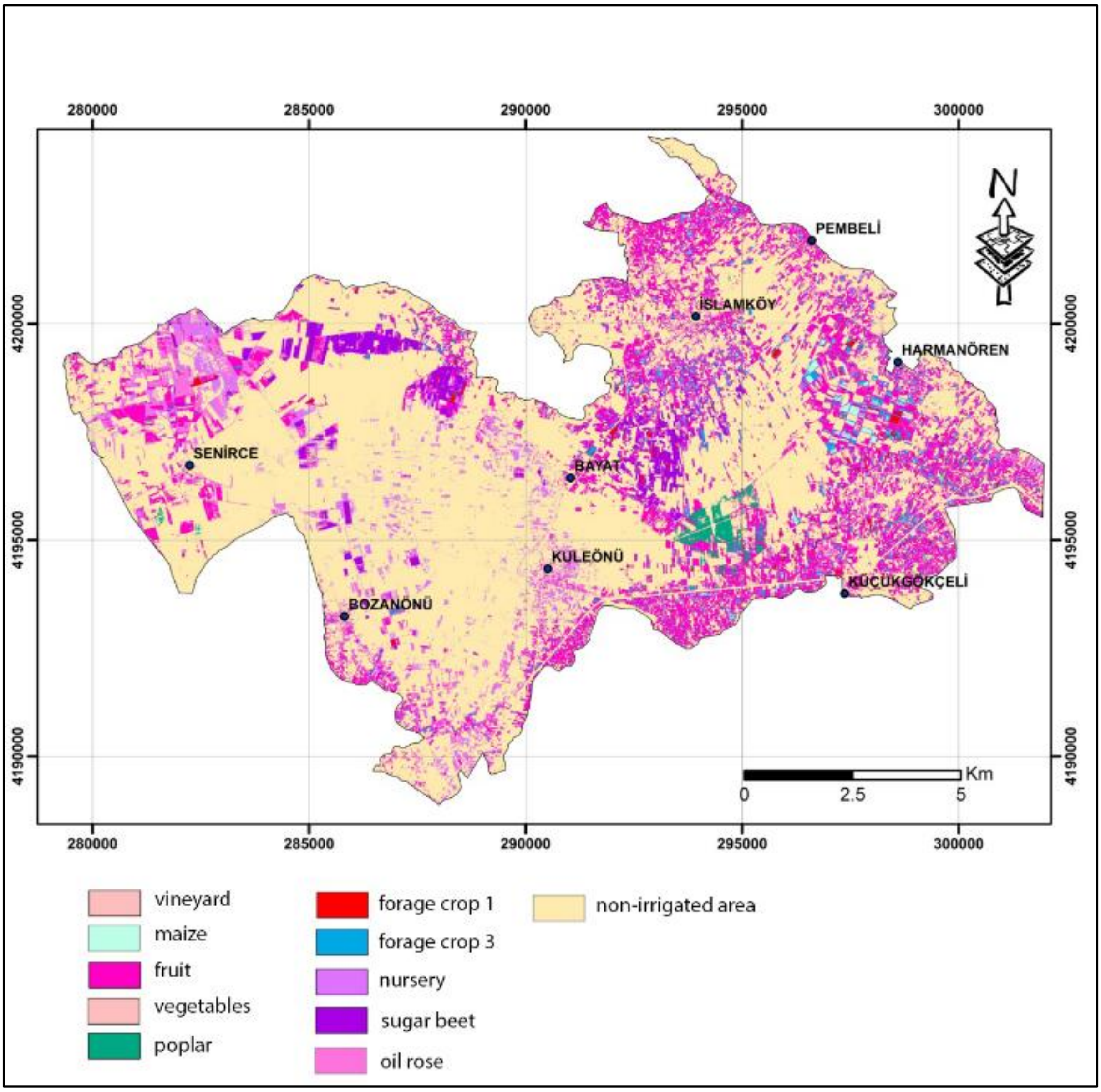

Figure 5. The crop pattern in the area where irrigated agriculture was performed within the scheme.

Since most of such field crops as barley and wheat in the non-irrigated area were harvested in July, when the image was taken, and as the soil properties underground differed, the number of classes in the satellite image turned out to be greater in the non-irrigated areas. Therefore, the 14 classes determined with supervised classification also by obtaining the location data, the fieldwork results, and the views of the field owners were categorized into 5 main groups, namely maquis, fallow (fallow 1 and fallow 2), cereals (cereal 1, cereal 2, cereal 3, cereal 4, and cereal 5), uncultivated land (uncultivated land 1, uncultivated land 2, uncultivated land 3, uncultivated land 4, and uncultivated land 5), and forage crop 2 (oat and common vetch). In the figures in Table 2, 28.81% of the non-irrigated areas within the scheme area are comprised of fallowing land; 32.31% of them are comprised of uncultivated land; and 33.73% of them are composed of cereal land. The rates of these classes in the total areas of the scheme are 19.09%, 21.42%, and 22.35%, respectively.

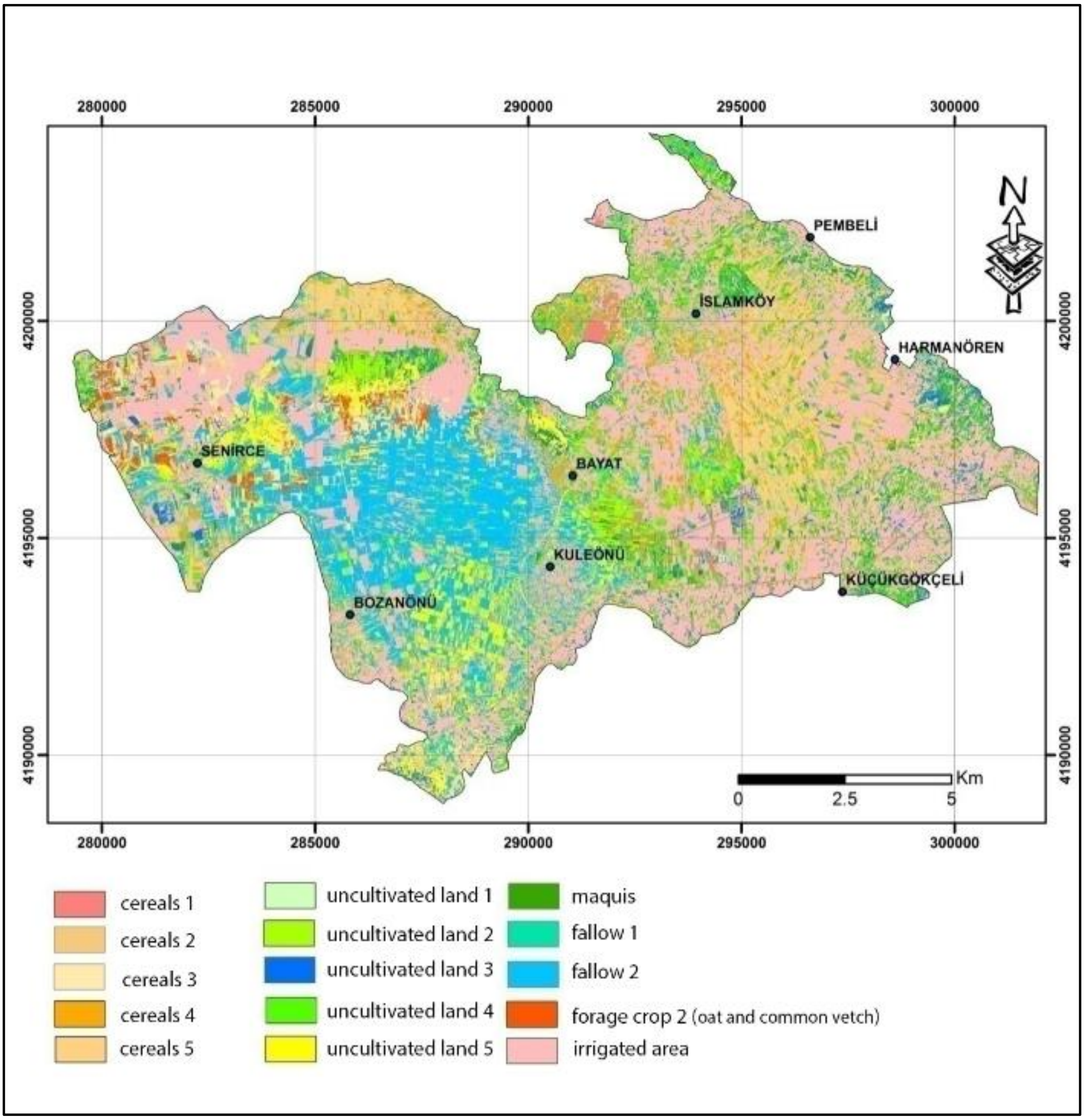

Figure 6. The crop pattern in the area where rainfed agriculture was performed within the scheme.

Table 2. The crop pattern in the area where rainfed agriculture was performed within the scheme

Crop classes	Area (ha)	Total areas (%)	Non-irrigated area (%)
Maquis	269.72	1.74	2.62
Fallow 1	146.59	0.94	1.42
Fallow 2	2820.60	18.15	27.39
Cereal 1	212.52	1.37	2.06
Cereal 2	524.23	3.37	5.09
Cereal 3	745.60	4.80	7.24
Cereal 4	895.85	5.76	8.70
Cereal 5	1095.43	7.05	10.64
Uncultivated land 1	3.97	0.03	0.04
Uncultivated land 2	426.86	2.75	4.14
Uncultivated land 3	636.90	4.10	6.18
Uncultivated land 4	1130.36	7.27	10.97
Uncultivated land 5	1130.66	7.28	10.98
Forage crop 2 (oat and common vetch)	260.44	1.68	2.53
Total	10299.74	66.28	100.00

Evapotranspiration

The evapotranspiration values of the crops irrigated at Atabey irrigation scheme that were calculated with Cropwat computer software by using the climatic data of 2012 are provided in Table 3. The highest seasonal evapotranspiration (860.7 mm) belonged to the forage crop (Alfalfa), followed by sugar beet (823.5 mm). On the other hand, nursery had the lowest seasonal evapotranspiration (476.3 mm). In general, the highest water consumption in all crops occurred in July, followed by August. On the other hand, the lowest water consumption values were recorded in April and October.

Table 3. Evapotranspiration values of the irrigated crops at Atabey irrigation scheme

Crops	Evapotranspiration, mm							
	Months							
	4	5	6	7	8	9	10	Total
Fruit	0	47.1	129.3	192.1	168.8	105.8	0	643.1
Maize	0	39.7	170.8	254.9	157	3.9	0	626.3
Vegetable	0	65.5	169.8	210.7	179.9	53.2	0	679.1
Vineyard	0	54.6	95.7	135.4	123.1	97.9	54.1	560.8
Forage crop	55.2	101.8	164.8	200.1	177	128.2	33.6	860.7
Sugar beet	19.9	48.4	156.5	232.5	205	132.6	28.6	823.5
Nursery	0	40.3	97.4	139.8	123	75.8	0	476.3
Oil rose	39.9	77.9	145.1	198.7	175.3	72.1	0	709.0
Poplar	22.8	43.6	82.6	154.4	156.7	121.5	70	651.6

Irrigation Performance

Relative water supply

Given the sum of the capacities of the right and left main canals (6.07 m^3 h^{-1}), it is seen that the total water amount likely to be let in the scheme between May and September was 80,240,544 m^3. Even though the capacity of the canal is 16,257,888 m^3 when Table 4 is examined, 17,000,000 m^3 of irrigation water was let in the scheme also using the air margin of the canals. One of the most used indicators in the evaluations made with respect to the water use by irrigation schemes is the RWS. The RWS below 1 indicates that less water than required has been supplied; those equal to 1 indicate that the water demand at the scheme has been fully met; and those greater than 1 indicate that more water than demanded has been applied (Beyribey et al., 1997; Degirmenci et al., 2003; Kuscu et al., 2009).

When the RWS values on a monthly basis at Atabey irrigation scheme in 2012 are examined, it is discovered that the scheme was not provided with water by the operator despite the presence of such crops as poplar, flower garden, sugar beet, and forage crop in April as well as such crops as vineyard, forage crop, sugar beet, and poplar in October within the irrigation area and in spite of the demand of these crops for 57,489 m^3 and 112,730 m^3 of irrigation water in April and October, respectively. The RWS ranged from 28.16 to 2.39 in May and September. The average RWS was found as 3.25 in 2012 (Table 4). When the climatic data of 2012 about the study area provided in the material and method section are examined, it is seen that the RWS in May was distinguished markedly from the others. When the rainfall in May 2012 is examined, it is seen that it was 107.4 mm in total. This value is more than twofold the average of long years. When calculating the irrigation water with Cropwat, the irrigation water requirements were calculated considering the rainfall. Nevertheless, it is seen that irrigation water was distributed in a way similar to that of the previous years in the operating of the irrigation scheme without taking the rainfall into consideration. It is thought that this difference in May might have been caused by this above-mentioned reason. Beyribey et al. (1997) found the RWS as 0.89, 0.95, and 1.03 for June, July, and August according to the total irrigation water requirement at 119 irrigation schemes in Turkey, respectively and Çakmak (2001) recorded the same ratio as 0.30-7.83 at Konya irrigation associations. Çakmak et al. (2004) calculated the RWS as 1.65-2.57 in the irrigation of the 10th Region of the DSI (the State Hydraulic Works) in another study, whereas Özdoğan (2010) calculated it as 2.10-24.01% in the irrigation of Güldürcek. The RWS values were found as 2.4-5.7 in Tanga and Weega (in Ghana) by Faulkner et al. (2008), as 0.37-0.85 at Karacabey irrigation scheme in 2002-2007 by Kuscu et al. (2009), as 1.2-1.5 at Bergama irrigation scheme by Karahan Uysal and Atış (2010), and as 1.70-2.60 at Gezira irrigation scheme in the Sudan by Al Zayed et al. (2015). Uçar (2011), however, found the annual water supply ratio as 3.22-3.63 in the irrigation applications in Isparta, also including Atabey irrigation scheme. The average RWS value of 3.25 found in the study area for 2012 means that 3.25 times more water than the water required by the crops was distributed to the scheme. This indicates that no efficient irrigation was carried out at the scheme for the year concerned. When the RWS values obtained in the study area for 2012 are compared with the studies summarized above, it is seen that the RWS values other than those in May are in agreement with the values obtained from the other studies.

Table 4. Relative water supply at Atabey irrigation scheme in 2012

Parameters	4	5	6	7	8	9	10	Annual
TIWR ×1000	57.5	42.6	3402.2	5647.3	3989.1	2515.0	112.7	15766.4
IWS ×1000	0	1200	12000	15000	17000	6000	0	51200
TCC ×1000	-	16257.9	15733.4	16257.9	16257.9	15733.4	-	80240.5
RWS ×1000	0.00	28.16	3.53	2.66	4.26	2.39	0.00	3.25

TIWR: Total irrigation water demand according to the existing irrigation ratio (33.72%), m^3; IWS: Irrigation water amount supplied to the scheme, m^3; TCC: Total canal capacity, m^3; and RWS: Relative water supply.

Financial efficiency performance

Besides the assessment of water use at irrigation schemes, it is desired that the financial efficiency of schemes be high as well. Of these efficiency values, the FCR and the FER are two important parameters which show the financial state of schemes. Table 5 provides the assessment, fee collection, operating, and maintenance expenses of Atabey irrigation scheme in 2012 as well as the FCR and the FER calculated by the help of these data. Svendsen and Nott (2000) reported that considering Turkey entirely, the average collection rate was found as 72%. The FCR values of the four water user associations located in western Anatolia in Turkey were found between 1.1 and 2.3 (Yercan, 2003). Karahan Uysal and Atış (2010) found the FCR as 94.2%-94.5% at Bergama irrigation scheme between 1993 and 2005. Yercan et al. (2004) determined the EFC and FSS values as 90 to 98% and 1 to 2.6 for eight irrigation schemes on the Gediz River Basin in western Turkey, respectively. Likewise, Çakmak et al. (2004) found the FCR as 41-68% in the irrigation of the 10th Region of the DSI. Whilst the FCR at the scheme in 2012 was 88.12%, the financial efficiency ratio was calculated as 1.42. Nalbantoğlu and Çakmak (2007) found the ratio of maintenance expenses to the revenue as 2.51-10.82% in the irrigation of Akıncı; Çakmak et al. (2009) recorded the ratio of investment to the revenue as 24-38% in the irrigation of Asartepe; Kapan (2010) calculated the ratio of maintenance expenses to the revenue as 31.6-543.19% and the fee collection ratio as 23-47% in the irrigation of Asartepe; and Çakmak and Tekiner (2010) found the fee collection ratio as 18-88% in the irrigation of Kepez, Çanakkale. It is seen that the results obtained from the research were in agreement with these results.

Table 5. Fee collection and assessment ratios of Atabey irrigation scheme in 2012

Fee collection	3021292.34	Assessment	3428522.97
Assessment	3428522.97	Operating and maintenance expenses	2410000.00
Fee collection ratio, %	88.12	Financial efficiency ratio, %	1.42

Conclusion

A database of Atabey irrigation scheme was generated and the irrigation performance of the scheme was determined by the help of it in this study, which investigated the possibilities of using the databases generated through the combination of Geographic Information Systems and Remote Sensing techniques in the performance assessment at irrigation schemes, as in many areas. When the water supply ratio was assessed, it was seen that it varied between 28.16 and 2.39 in May and September and the mean water supply ratio was calculated as 3.25. It was established that the water supply ratio in May was substantially great as compared with those in the other months. It was concluded that this was because the rainfall in May 2012 was more than twofold the average of long years but that the irrigation water was distributed in a way similar to that of the previous years in the operating of the irrigation scheme without considering this situation. At the end of the study, it was concluded that remote sensing and geographic information systems could be used in the performance assessment of irrigation schemes.

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