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Determination of Adequacy and Equity of Water Delivery in Irrigation Systems: A Case Study of the Gediz Basin

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Abstract: This study assesses the water delivery performance of four selected Water User Associations (WUAs) in the Gediz Basin irrigation system from the point of view of adequacy and equity for the years 2004 and 2005, using remote sensing techniques. Adequacy of water delivery was determined according to Irrigation Ratio (IR), Water Use Ratio (WUR) and average of Normalized Difference Vegetation Index ($NDVI_{ave}$) and equity according to values of the coefficient of variation of NDVI (CV_{NDVI}). IR values for the WUAs varied between 48 and 89% each year, averaging 77% in 2004 and 76% in 2005. WUR values for the selected WUAs varied from month to month each year, with seasonal average values close to or greater than 1. $NDVI_{ave}$ values for all WUAs were higher in 2004 (0.32 as against 0.42). CV_{NDVI} values for 2004 varied between 0.14 and 0.23 and for 2005 between 0.14 and 0.30. The IR indicator showed that a WUA located at the end of a main canal which served more than one WUA did not receive adequate water. The WUR indicator showed that while the amounts of water supplied during the season to the selected WUAs were close to the amounts planned, in both seasons water was not supplied homogeneously month by month. The $NDVI_{ave}$ indicator showed that the selected WUAs were more successful in supplying water adequately in 2004. Finally, the CV_{NDVI} indicator showed that the selected WUAs were parallel in terms of equity in both years; that is, it showed that a given WUA showed the similar success level each year.

Key words: Water delivery performance, adequacy, equity, remote sensing, Gediz Basin

INTRODUCTION

The purpose of performance assessment is to achieve efficient, productive and effective irrigation and drainage systems by providing relevant feedback to management at all levels. As such, it may assist management or policy makers in determining whether performance is satisfactory and, if not, which corrective actions need to be taken in order to remedy the situation (Bos *et al*., 2005).

In many countries, accurate evaluation of irrigation system performance and sustainability is hampered by lack of adequate, reliable and timely irrigation statistics. Usually, performance indicators such as yield, cropping intensity and irrigation intensity are measured at an aggregated level, often at the state or national levels. Data at project level are rarely collected. If collected, they are frequently unreliable or not easily accessible (Murray-Rust and Merrey, 1994).

Satellite remote sensing provides the opportunity to capture the information of a large area at frequent intervals. The capability of satellite remote sensing to monitor agricultural and hydrological conditions of the land surface has undergone major improvements in the present decade. The following areas of irrigation water management using remote sensing techniques have been addressed: identification of irrigated crops, storage in reservoirs, irrigated crop areas, crop condition and yield, crop water requirement, soil moisture, water logging and soil salinity irrigation system performance (Ambast *et al*., 2002), strategic planning and water rights, water use and productivity, impact assessment, precipitation, runoff, crop coefficient and biomass (Karatas *et al*., 2003).

Crop conditions depend on the amount of soil moisture available to the crop during the growing season. The source for the soil moisture is either precipitation or irrigation. When crops are irrigated and their soil moisture requirements are completely met, the spatial distribution of their health conditions is rather uniform. Various indices have been developed using AVHRR data to monitor crop or vegetation conditions over large areas. Out of these indices, the Normalized Difference Vegetation Index (NDVI) has been widely used for vegetation monitoring (Boken *et al*., 2004).

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In Turkey, data relating to Water User Associations (WUAs) such as crop pattern, irrigation ratio and water supplied to the system at main canal level are kept by the General Directorate of State Hydraulic Works (DSI), but it is impossible to find information on water delivery within the system. In this study, water delivery performance of four selected WUAs in the Lower Gediz Irrigation System, located in the Gediz Basin, one of the country's important catchment areas, has been assessed according to the indicators of adequacy and equity.

MATERIALS AND METHODS

Material: The Gediz Basin, located in the west of Turkey, covers an area of 17200 km^2, with 140000 ha under irrigation. Altitude ranges from sea level to 2300 m. Annual precipitation ranges from 1000 mm on the mountains to 500 mm in the coastal areas and the area has a Mediterranean climate.

Sources of water for irrigation in the basin are the multi-purpose Demirköprü Reservoir and Gölmarmara Lake, along with the Afşar and Buldan irrigation reservoirs. Principal crops are, in order of importance, cotton, grapes, cereals, other fruit and vegetables, olives, tobacco and melons. The natural vegetation is mainly composed of brush and forest (Droogers *et al*., 2000).

Operation of the Gediz Basin irrigation system was transferred from the DSI to 13 WUAs in 1995. The present study was carried out on the irrigation areas of four selected WUAs of the Lower Gediz Irrigation System. These were, from upstream to downstream, the Salihli Left and Right Bank WUAs at the head, the Gediz WUA in the middle and the Menemen Left Bank WUA at the end. Irrigation water in the Lower Gediz Irrigation System is delivered from the Demirköprü Reservoir via the Adala, Ahmetli and Emiralem regulators and six main canals connected to them. In months of intensive irrigation, Gölmarmara Lake is brought into use (Fig. 1).

The study has made use of DSI records of planned delivery and actual flow records along with low-resolution (1.1 km at nadir) NOAA-16/AVHRR images. These satellite images were obtained from http://www.class.noaa.gov.

Methods: In assessing the water delivery performance of the WUAs regarding adequacy, irrigation ratio (IR), water use ratio (WUR) (Jurriens, 1996) and average NDVI ($NDVI_{ave}$) were used, while equity was assessed using the variation coefficients of NDVI, which showed whether water delivery was uniform in the area served by the WUAs (Sakthivadivel *et al*., 2001).

IR and WUR were calculated using the following equations:

$$IR = \frac{\text{Actual irrigated area (ha)}}{\text{Projected irrigation area (ha)}}$$

$$WUR = \frac{\text{Actual water use } (m^3 ha^{-1})}{\text{Target water use } (m^3 ha^{-1})}$$

The normalized difference vegetation index (NDVI) is a measure of the amount and vigor of vegetation at the surface. It is formulated as follows:

$$NDVI = (R_{NIR}-R_{red}) / (R_{NIR}+R_{red})$$

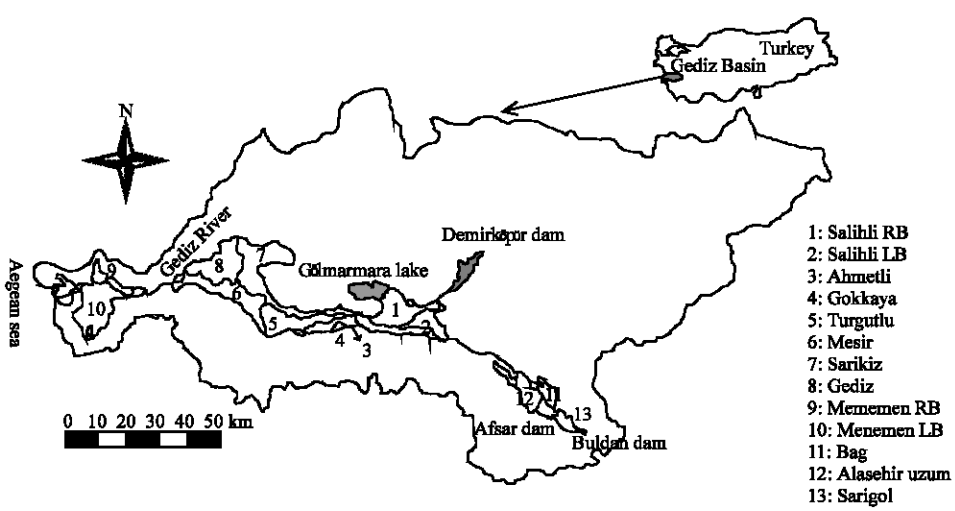


Fig. 1: Location of the WUA's in the Gediz Basin

Where R is the reflectance value in the indicated band. Index values can range from -1.0 to 1.0. The magnitude of NDVI is related to the level of photosynthetic activity in the observed vegetation. In general, higher values of NDVI indicate greater vigor and amounts of vegetation. The reason NDVI is related to vegetation is that healthy vegetation reflects very well in the near infrared part of the spectrum (Parodi, 2002). As the leaves come under water stress, become diseased or die back, they become more yellow and reflect significantly less in the near infrared range.

In calculating $NDVI_{ave}$ and CV_{NDVI} values, an equal number of pixels (35 pixels) forming a rectangle was determined within the irrigation area of each WUA on the NDVI maps which were drawn. $NDVI_{ave}$ and CV_{NDVI} values were calculated with reference to the NDVI values of these pixels. NOAA-16/AVHRR images used in the study had undergone pre-processing in order to correct the geometric distortions, calibrate the data radiometrically and eliminate the noise and clouds that present in the data (Gautam *et al*., 2006). WinCHIPS software was used for this process and NDVI maps were drawn using ILWIS software.

RESULTS AND DISCUSSION

Adequacy of water delivery: The adequacy of delivery of water to the irrigated areas of the four WUAs in the Lower Gediz Irrigation system is evaluated below according to the indicators of IR, WUR and $NDVI_{average}$.

Irrigation ratio (IR): It can be seen from Table 1 that IR values varied from 48 to 89%, with averages of 77% in 2004 and 76% in 2005. The lowest IR values for each year came from Gediz WUA. The main factor causing these low values is that the Gediz WUA is at the end of a main canal which also serves three other WUAs and thus it gets insufficient water. Apart from this WUA, there is no important difference in irrigation ratios between WUAs according to their distance from the source.

Water use ratio (WUR): The WUR values of the selected WUAs show variations between the two years and from month to month, but seasonal averages were generally close to 1 (Table 2).

Table 1: IR values (%) for the irrigation seasons 2004 and 2005

Name of WUA	2004	2005
Salihli RB	89	86
Salihli LB	78	83
Gediz	52	48
Menemen LB	88	88
Average	77	76

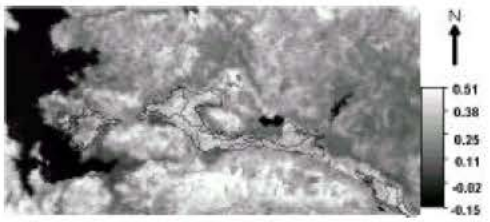
If WUR value was equal to 1, this showed that the amount of water delivered per unit of irrigated area was same to the planned amount; a value less than 1 shows that less water was delivered than planned, while a value greater than 1 indicates that more water was delivered than planned (Jurriens, 1996). Thus it can be seen that in 2004 the amount of water delivered per unit of irrigated area in the selected WUAs was closer to the planned amount than in 2005, but in both years water was not delivered homogeneously month by month over the season. Water was delivered to the system in excess of the plan in both years, particularly in August. This can be seen especially clearly in the case of the Salihli Right Bank and Salihli Left Bank WUAs, which are close to the source. When monthly WURs are compared, it can be seen that 2004 was a more successful year from the point of view of adequacy.

Average of NDVI ($NDVI_{ave}$): $NDVI_{ave}$ values were calculated for the four selected WUAs for the 2004 and 2005 irrigation seasons for five images, three in July and two in August, when irrigation was most intensive and also vegetative development was at a maximum for the season (Fig. 2 and 3) and results are given in Table 3. Monthly $NDVI_{ave}$ values show an increase from the beginning of July to the end of August. Seasonal values varied between 0.32 and 0.42 for 2004 and between 0.26 and 0.42 for 2005. $NDVI_{ave}$ values for all WUAs were higher in 2004. High NDVI represents good crop condition and hence better productivity (Sakthivadivel, 2001). Thus it can be seen that crop condition was better in 2004 than in 2005; in other words, water delivery in the selected WUAs was better as regards adequacy in the 2004 irrigation season.

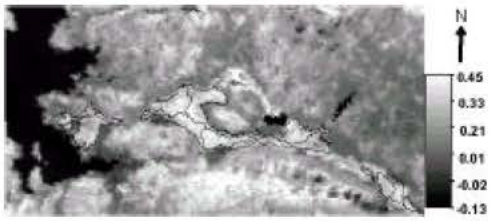
Equity in water delivery: The equity of delivery of water supplied to the irrigated areas of the four selected WUAs is assessed below using the CV_{NDVI} performance indicator.

Table 2: WUR values for the irrigation seasons 2004 and 2005

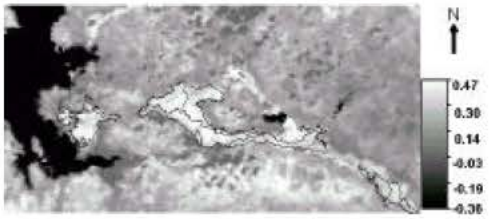
	2004					2005				
Name of WUA	June	July	Aug.	Sept.	Season	June	July	Aug.	Sept.	Season
Salihli RB	0.99	0.99	1.34	0.42	1.03	0.45	0.80	1.45	0.94	0.88
Salihli LB	0.87	0.97	1.33	1.38	1.03	0.71	0.86	1.49	1.34	0.97
Gediz	0.87	1.08	1.01	0.49	0.95	0.56	1.11	1.05	0.05	0.86
Menemen LB	0.66	1.04	1.01	0.62	0.89	0.60	1.19	1.18	0.27	0.94



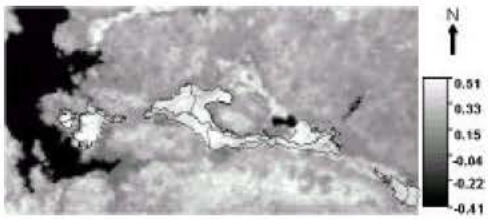
a) July 3, 2004



b) July 12, 2004



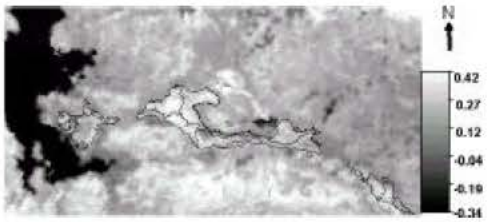
c) July 28, 2004



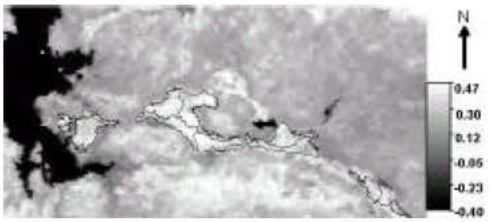
d) August 14, 2004

e) August 25, 2004

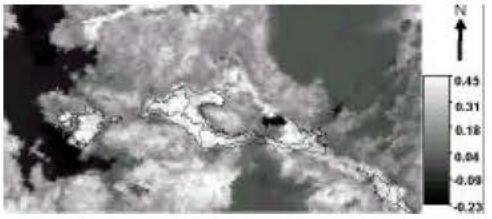
Fig. 2: NDVI maps for the irrigation season 2004



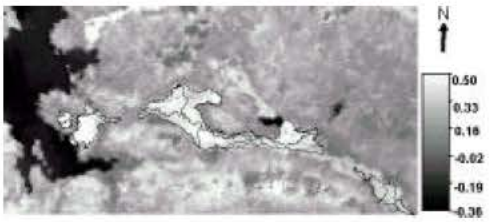
a) July 2, 2005



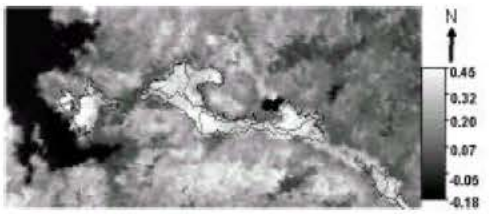
b) July 19, 2005



c) July 30, 2005



d) August 16, 2005



e) August 26, 2005

Fig. 3: NDVI maps for the irrigation season 2005

Table 3: $NDVI_{ave}$ and CV_{NDVI} values for the irrigation seasons 2004 and 2005

		2004						2005					
Name of WUA	Indicator	J03	J12	J28	A14	A25	Season Ave.	J02	J19	J30	A16	A26	Season Ave.
Salihli RB	$NDVI_{ave}$	0.32	0.36	0.42	0.48	0.52	0.42	0.26	0.36	0.40	0.45	0.39	0.37
	CV_{NDVI}	0.12	0.11	0.18	0.15	0.13	0.14	0.19	0.17	0.20	0.18	0.23	0.19
Salihli LB	$NDVI_{ave}$	0.27	0.27	0.31	0.36	0.41	0.32	0.15	0.26	0.27	0.31	0.31	0.26
	CV_{NDVI}	0.27	0.24	0.22	0.24	0.19	0.23	0.33	0.27	0.33	0.26	0.29	0.30
Gediz	$NDVI_{ave}$	0.36	0.36	0.42	0.44	0.49	0.41	0.43	0.43	0.41	0.45	0.36	0.42
	CV_{NDVI}	0.22	0.18	0.14	0.13	0.11	0.16	0.16	0.12	0.17	0.13	0.11	0.14
Menemen LB	$NDVI_{ave}$	0.23	0.25	0.39	0.45	0.54	0.37	0.15	0.31	0.38	0.51	0.42	0.35
	CV_{NDVI}	0.30	0.28	0.18	0.22	0.08	0.21	0.27	0.16	0.16	0.20	0.19	0.19

Variation coefficients of NDVI (CV_{ANDVI}): CV_{NDVI} values for the 2004 and 2005 irrigation seasons of the four WUAs studied are presented in Table 3. In 2004, the WUAs' season average coefficients of variation ranged from 0.14 to 0.23 and in 2005 from 0.14 to 0.30. When the two years are taken together, it can be seen that the coefficient of variation was low particularly in the irrigated area of the Gediz WUA and crop condition and, related to it, water delivery, were more homogeneous; that is, this WUA was more successful from the point of view of equity of water delivery. The reason why the coefficient of variation of the Salihli Left Bank WUA was higher is that it was less successful in terms of equitable water delivery.

CONCLUSIONS

This study assesses the water delivery performance of four selected WUAs in the Gediz Basin irrigation system from the point of view of adequacy and equity for the years 2004 and 2005, using remote sensing techniques. Adequacy of water delivery was determined according to irrigation ratio, water use ratio and average of Normalized Difference Vegetation Index and equity according to values of the coefficient of variation of NDVI. The study showed that irrigation ratio values for a selected WUA were related to its location on the main canal rather than their distance from the source. According to this indicator, a WUA located at the end of the main canal is in a worse condition with regard to adequacy. According to WUR and $NDVI_{ave}$ indicators, WUAs were more successful in terms of adequacy in 2004. Also, there was a parallel between the two years regarding equity. That is, a WUA which was unsuccessful in 2004 was also unsuccessful in 2005 and a WUA which was successful in 2004 was successful in 2005 too.

Only if studies like this are carried out over many years in the Basin will more comprehensive assessment of the WUAs' water delivery performance according to the selected indicators be possible.

REFERENCES

Ambast, S.K., A.K. Keshari and A.K. Gosain, 2002. Satellıte Remote Sensing to Support Management of Irrigation Systems: Concepts and Approaches. Irrig. Drain., 51: 25-39.

Boken, V.K., G. Hoogenboom, F.N. Kogan, J.E. Hooks, D.L. Thomas and K.A. Harrison, 2004. Potential of using NOAA-AVHRR data for estimating irrigated area to help solve an inter-state water dispute. Intl. J. Remote Sensing, 25: 2277-2286.

Bos, M.G., M.A. Burton and D.J. Molden, 2005. Irrigation and Drainage Performance Assessment: Practical Guidelines, CABI Publishing .

Droogers, D.D., G. Kite and H. Murray-Rust, 2000. Use of Simulation Models to Evaluate Irrigation Performance Including Water Productivity, Risk and System Analyses. Irrig. Sci., 19: 139-145.

Gautam, R.S., D. Singh and A. Mittal, 2006. Detection of hotspots in NOAA/AVHRR images using principal component analysis and information fusion technique. International Symposium on Geospatial Databases for Sustainable Development GOA, September 27-30, 2006, India.

Jurriens, R., 1996. Assessing Seasonal Irrigation Service Performance, Working Papers on Irrigation Performance 3, IFPRI, Washington, D.C.

Karataş, B.S., Ş. Aşık,, H.B. Ünal and M. Avcı, 2003. Using remote sensing on management of irrigation systems. International Congress on Information Technology in Agriculture, Food and Environment, 7-10 October, İzmir.

Murray-Rust, H. and D.J. Merrey, 1994. Irrigated agriculture beyond 2000: Institutional adaptation and transformation. IIMI Rev., 8: 21-28.

Parodi, G.N., 2002. AHVRR Hydrological Analysis System-Algorithms and Theory-Version 1.3 WRES- ITC.

Sakthivadivel, R., Amarasinghe, A. Upali and S. Thiruvengadachari, 2001. Using remote sensing techniques to evaluate lining efficacy of watercourses. Research Report 46, International Water Management Institute. Colombo, Sri Lanka.