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Using Remote Sensing and GIS for Assessment of Irrigation Performance in the Al-Hindiyah Barrage, Babil City, Iraq

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Abstract: Problems and concerns over water lack would affect irrigated agriculture. Iraq suffers from shortage water and the principle use of water is for irrigation. Hence, better performance of irrigation saves more water, which can be used for other purposes. The objective of the research is to assess the irrigation performance in Al-Hindiyah barrage located in Babil city, in middle of Iraq using GIS and remote sensing. In order to achieve this objective, performance of the irrigation season for 2014 was defined upon five indicators, namely relative water supply, general consumed ratio, relative evapotranspiration, depleted fraction and crop water deficit. Actual and potential parameters of evapotranspiration used in determination of these indicators were estimated depending on the method of Surface Energy Balance Algorithm for Land (SEBAL) by using a series of Landsat OLI satellite images. The range of seasonal averages of these indicators was between (0.138 and 2.704) for overall consumed proportion (0.395-7.129) for relative water supply (0.061-1.136) for depleted fraction (0.407-0.464) for relative evapotranspiration and (200.757-247.474) mm/month for crop water deficit. The result of this study indicated that the performance of the irrigation was poor according to the average of seasonal values of all performance indicators. The performance indicators revealed that the supplied irrigation water was less than needed. Thus, it was determined that nearness to the source might be an advantage to obtain water, and there should be a concurrence between the period when water is provided and the period when it is needed.

Key words: Irrigation performance, actual evapotranspiration, SEBAL, remote sensing, GIS

INTRODUCTION

In semi-arid areas, irrigation water is often provided by collective Large-Scale Irrigation (LSI) Systems that are considered to have low levels of management performance Nakashima (2000). Thus, performance assessment is considered one of the most critical elements for improving irrigation management Abernethy and Pearce (1987). The integration of RS data and GIS tools to compute performance indices could provide irrigation managers with the means for managing efficiently the irrigation system Ray. Likewise, remote sensing data are widely distributed at different scale and spatial levels which make possible to use for assessing the performance of large irrigation systems. The assessment of evapotranspiration (ET) which remote sensing data provides on large spatial scales, from irrigation district to entire basin or region provides support for water management at different decision levels. Water productivity analysis, irrigation scheduling, irrigation planning and water allocation can also be tackled only if timely and accurate information about water consumption by crops is available Gonzalez-Dugo. In a study by Ahmad *et al*. (2006) such data combined together with climate data and used in the application of surface energy balance techniques to map spatial and temporal variation in actual Evapotranspiration (ETa). The analysis shows that these data can be effectively combined with secondary cropping statistics that have been suitably transformed from their administrative domain to a hydrographic one. Surface energy balance applied to derive potential evapotranspiration not only the actual evapotranspiration. For example, MODIS satellite data, which is publically available, used to derive potential evapotranspiration. However, not only surface energy techniques used for evapotranspiration derivation from satellite data, other author tried different methods.

Several models for the derivation of ET using satellite data have been developed. Empirical models relate daily

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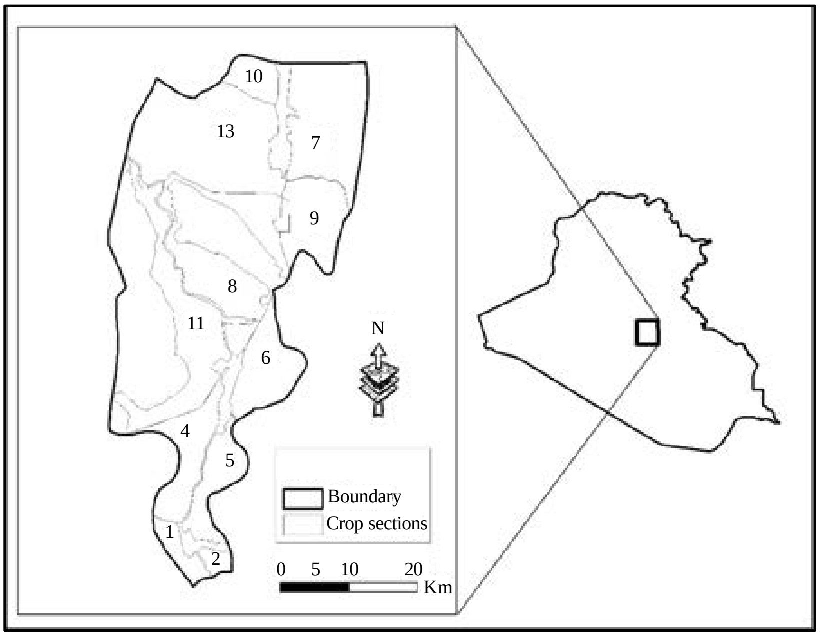

Fig. 1: Location of study area

ET or sensible heat flux directly to an instantaneous surface temperature. These simple models mostly deal with and rely on homogeneous surfaces (Ambast *et al*., 2002). The Surface Energy Balance Algorithm for Land (SEBAL) method for heterogeneous surfaces was developed based on the surface energy balance on an instantaneous time basis integrated over the day for the estimation of ET on a daily basis. This overcomes dependency on detailed meteorological measurements, information on crop types and application to small areas (Bastiaanssen *et al*., 2001).

Regarding the assessment of irrigation performance using remote sensing data and GIS techniques, many authors have proposed indicators to measure irrigation system performance (Bos *et al*., 1994; Beyribey and Cakmak, 1996; Molden and Gates, 1990; Rao, 1993; Molden *et al*., 1998). Assessed the irrigation performance of the Water User Associations (WUAs) in the Lower Gediz Basin in Western Turkey, using remote sensing techniques. The performance of the irrigation system for the 2004 irrigation season was determined according to five indicators, namely overall consumed ratio (ep), Relative Water Supply (RWS), Depleted Fraction (DF), Crop Water Deficit (CWD) and Relative Evapo Transpiration (RET). Potential and actual evapotranspiration parameters used in determining these indicators were estimated according to the Surface Energy Balance Algorithm for Land (SEBAL) Method using NOAA-16 satellite images.

The objective of this study is to evaluate the irrigation performance by using GIS and remote sensing in the Al-Hindiyah barrage, Iraq because the evaluation of irrigated areas is important in improving and identifying the irrigation performance to reach optimal productivity in various contexts. The outcomes of this research would be important for decision makers to enhance the irrigation managementin the study area.

Study area: The study area is a part of the sedimentary plain in Iraq which formed due to the deposition of the Tigris and Euphrates operations as shown in Fig. 1. These operations also identified the nature of the ground surface and the global plain of the ground surface. The topography of the ground surface contrasting bands on the rise, the scope of the shoulders of two natural rivers formed through sedimentation during floods that were exposed to conservative. The study area is one of the most suitable surface sections of the agricultural side due to the quality of soil and low level of the water table. Temperature rates characterized by low annual rates in the winter to reach in the month of January at (10.5°) and then begin to rise gradually to reach the highest in July and August at (34.7°). On the other hand, the rain in the study area begins to fall in the month of October but they are rare and do not constitute only about 4.5% of the annual total which amounts to (102.1 mm) and ends in the month of June increased by not more than (0.09%). Irrigation and drainage network is distributed in the province of Babylon in almost all parts of the province. This is due to the abundance of surface water because of the role of the Euphrates river and the Al-Hindiyah barrage as well as the need for this network to irrigate agricultural areas in the province. Irrigation network of Babil characterized as branching directly from the Euphrates river with a length within the limits quench the province about 121 km. taking advantage of the high elevations of the water provided by the Al-Hindiyah barrage.

MATERIALS AND METHODS

Ancillary data: Remote sensing data is not enough to evaluate an irrigation system. Therefore, ancillary data are required to have for the performance evaluation of an irrigation system such as climate data during the satellite pass date of the captured images. Daily climate data for the study area were first collected from the Iraqi metrological department. The average climate data for the study area as shown in Table 1. Beside the climate data, the amount of water diverted to each crop sector also necessary. Diverted water amount for the crop sections (Vc), Pg (gross Precipitation) and Pe (effective Precipitation) were collected from Ministry of Water Resources in Iraq as shown in Table 2. These data captured on 2014 and for four different months (irrigation season) which are the months to be studied in this research (March, May, July and September) because Iraq has four different seasons in a year.

Remote sensing data: On the other hand, remote sensing data is required to calculate the parameters needed to evaluate the performance of an irrigation system at each pixel element level. In this study, a series of Landsat OLI data are used because the area of the region is quite large and this data is free to cover all part of the study area. The spatial resolution of this sensor is 30 m which is enough to evaluate the irrigation system with acceptable accuracy. Table 3 shows the date and the characteristics of the data downloaded from USGS website (available at www.usgs.com).

Table 1: Average climate data of the studied time period

Month	Tmean (°C)	RH mean (%)	U2 $msec^{-1}$	ea kPa	es kPa	RS MJ/m^2 day
March	17.40	47.00	2.90	0.934	1.987	18.05
May	29.00	31.00	3.10	1.242	4.006	26.82
July	34.30	25.00	4.00	1.352	5.409	26.66
September	32.10	28.00	3.10	1.339	4.782	19.46
Average	28.20	32.75	3.28	1.220	4.050	22.75

Table 2: Diverted water to sections during the studied time period

	Water diverted from regulator (V_c (mm))				
Sections	March	May	July	September	Total
1	66.03	440.20	550.25	143.07	1199.55
2	30.35	202.37	252.96	65.77	551.45
3	156.34	1042.28	1302.85	338.74	2840.21
4	413.51	2756.76	3445.95	895.95	7512.17
5	616.67	4111.11	5138.88	1336.11	11202.77
6	212.11	1414.10	1767.62	459.58	3853.41
7	203.64	1357.58	1696.97	441.21	3699.40
8	382.99	2553.24	3191.55	829.80	6957.59
9	216.86	1445.73	1807.17	469.86	3939.62
10	86.87	579.12	723.89	188.21	1578.09
11	369.83	2465.54	3081.93	801.30	6718.60
Average (mm)	250.47	1669.82	2087.28	542.69	4550.26
P_g (mm)	31.74	19.05	1.98	0.83	53.60
P_e (mm)	19.95	16.88	2.00	0.99	39.81

Calculation of potential evapotranspiration: The potential Evapotranspiration rate (Etp) is estimated by the Penman-Monteith according to Eq. 1:

$$ET_p = \frac{\frac{\Delta_v}{\lambda_w}(R_n - G) + \frac{p_1 \rho_{air} C_{air}}{\lambda_w}\frac{e_{air} - e_a}{r_{air}}}{\Delta_v + \gamma_{air}(1 + \frac{r_{crop}}{r_{air}})} \quad (1)$$

Where:

- Δ_v = The slope of the vapor pressure curve
- λ_w = The latent heat of vaporization
- R_n = The net radiation flux density above the canopy
- G = The soil heat flux density
- p_1 = Accounts for unit conversion (= 86,400 s d-1)
- ρ_{air} = The air density
- C_{air} = The heat capacity of moist air
- e_s = The saturation vapor pressure
- e_a = The actual vapor pressure,
- r_{air} = The aerodynamic resistance
- γ_{air} = The psychometric constant
- r_{crop} = The crop resistance

In order to solve this equation, daily weather data of solar radiation, vapor pressure and wind speed and air temperature are required. In addition, crop characteristics such as minimum resistance, reflectance (albedo) and crop height are needed.

Calculation of actual evapotranspiration: SEBAL is used for actual evapotranspiration calculations which is a well-tested and widely used method to compute ET_a (Bastiaanssen, 1998, 2002, 2005; Allen *et al*., 2007; Tasumi, 2003; Ahmad *et al*., 2006). Since, the satellite image

Table 3: Series of Landsat images over the study area

Remote sensing data	Acquired date	Path/raw	Cloud cover (%)	Spatial resolution (m)
Landsat OLI Scene 1	2014-03-23	168/37	0.21	30
Landsat OLI Scene 2	2014-05-17	169/37	0.17	30
Landsat OLI Scene 3	2014-07-20	169/37	0.23	30
Landsat OLI Scene 4	2014-09-22	169/37	0.19	30

provides information for the overpass time only, SEBAL computes net Radiation (R_n), sensible Heat flux (H) and soil heat flux (G) for every pixel and the Latent heat (LE) is acquired as a residual in energy balance as shown in Eq. 2:

$$R_n = LE + H + G \tag{2}$$

Where:

LE = Latent heat flux (ET in energy units)
R_n = Net radiation at the surface
H = Sensible heat flux to the air
G = soil heat flux (Wm-2)

Irrigation performance indicators: Irrigation performance was determined according to the indicators of overall consumed ratio (ep) (Bos and Nugteren, 1990), Relative Water Supply (RWS) (Perry, 1996), Depleted Fraction (DF), Crop Water Deficit (CWD) (Bastiaanssen, 2001) and Relative Evapotranspiration (RET) (Roerink *et al*., 1997) which were calculated using parameters of ET_a and ET_p derived from satellite remote sensing.

Overall consumed ratio (ep): Overall consumed ratio quantifies the degree to which crop irrigation requirements are met by irrigation water in the irrigated area (Bos and Nugteren, 1990). The ratio is defined in Eq. 3 as follows:

$$e_p = \frac{ET_p - P_e}{V_C} \tag{3}$$

Where:

ET_p = Potential evapotranspiration (mm)
P_e = Effective precipitation (mm)
V_C = Volume of irrigation water diverted from resource (mm)

If the supply is sufficient, the ep value will be around 1.0.if it is greater than 1.0, it indicates under irrigation, whereas value <1.0 indicates over irrigation.

Relative Water Supply (RWS): The relative water supply used as an indicator of adequacy of irrigation water delivery compares supplied water with that demanded (Perry, 1996). It is calculated in Eq. 4 as follows:

$$DF = \frac{ET_a}{V_c + P_g} \tag{4}$$

where, P_g is gross precipitation in mm. The target value of the RWS indicator were considered as 2.0 (Molden *et al*, 1998).

Depleted Fraction (DF): Depleted fraction shows changes in actual water use by crops and quantifies differences in the water balance of the areas under study (Bandara, 2006). The depletion in an irrigation scheme is governed by ET_a. This indicator is defined in Eq. 5 as follows (Molden, 1997):

$$CWD = ET_p - ET_p \tag{5}$$

where, ET_a is actual evapotranspiration in mm. DF should be considered as a function of time. For semi-arid and arid regions the critical value of the depleted fraction averages about 0.6 (Bos *et al*., 2005). The acceptable range of DF was considered as 0.6-1.1 (Bastiaanssen *et al*., 2001).

Crop Water Deficit (CWD): Crop water deficit over a period is defined as the difference between ET_p and ET_a of the cropping pattern within an area. A common period is 1 month and an average CWD of 30 mm month^{-1} is acceptable (Bastiaanssen *et al*., 2001). Equation 6 defines crop water deficit as follows:

$$CWD = ET_p - ET_p \tag{6}$$

Relative Evapotranspiration (RET): Relative evapotranspiration quantifies reduction in evapotranspiration and detects water-short areas (Bandara, 2006). To evaluate the adequacy of irrigation water delivery to a selected command area as a function of time, the dimensionless ratio of ET_a over ET_p gives valuable information to the water manager (Roerink *et al*., 1997). Relative evapotranspiration ET is defined in Eq. 7 as follows:

$$RET = \frac{ET_a}{ET_p} \tag{7}$$

A value of RET = 0.75 is quite acceptable for irrigated agriculture in the growing season, although this is not constant over time (Roerink *et al*., 1997). In the equations, ET_a and ET_p were derived from satellite RS.

RESULTS AND DISCUSSION

Seasonal as well as monthly values of the V_C, P_g and P_e parameters required to analyze the selected indicators of the irrigation performance for the irrigation season of 2014 are shown in Table 2. Results of seasonal and monthly values of the ET_p and ET_a parameters required to analyze the indicators of the irrigation

Table 4: Results of potential evapotranspiration

	ET_p (mm)				
Sections	March	May	July	Sep.	Total
1	256.3700	397.7300	512.1200	370.50	1536.72
2	249.5500	396.8000	516.7700	368.40	1531.52
3	252.0300	396.1800	508.4000	367.50	1524.11
4	241.4900	418.5000	556.1400	398.40	1614.53
5	248.9300	399.2800	547.4600	383.10	1578.77
6	260.0900	390.2900	517.7000	358.50	1526.58
7	253.2700	384.4000	496.9300	363.60	1498.20
8	255.1300	389.6700	525.1400	362.70	1532.64
9	257.9200	413.5400	562.9600	394.20	1628.62
10	273.4200	433.3800	564.2000	398.40	1669.40
11	263.5000	404.5500	534.1300	383.70	1585.88
Average (mm)	255.6091	402.2109	531.0864	377.18	1566.08

Table 5: Results of actual evapotranspiration

	ET_p (mm)				
Sections	March	May	July	Sep.	Total
1	64.20100	162.9670	211.9470	250.1700	689.2850
2	64.26300	162.5330	211.5440	249.5100	687.8500
3	64.63500	162.7190	211.6990	249.1200	688.1730
4	64.44900	162.3160	211.2960	247.1400	685.2010
5	64.17000	161.1690	210.1490	246.1800	681.6680
6	64.35600	161.5100	210.4900	245.8800	682.2360
7	64.69700	164.6720	213.6520	252.1500	695.1710
8	63.79800	161.4170	210.3970	246.5400	682.1520
9	64.51100	161.6960	210.6760	246.5100	683.3930
10	64.20100	161.0760	210.0560	244.1700	679.5030
11	63.51900	160.7660	209.7460	246.9600	680.9910
Average (mm)	64.25455	162.0765	211.0593	247.6664	685.0566

performance are shiwn in Table 4 and 5, respectively for the irrigation season of 2014. Also, daily Et_a and ET_p maps of the complete study area for months (March, May, July and September) are shown in Fig. 2 and 3, respectively. Values of ET_a and ET_p vary among pixels because of the difference in the vegetative growth, crop pattern, conditions weather as well as other factors. Results of monthly and seasonally for irrigation performance indicators are shown in Table 6 and 7 respectively. Discussion of results various irrigation performance indicators as following.

Overall consumed ratio (ep): As the first measurement in the irrigation system is total water supply, first available indicator in every irrigated area might be the ep. Table 6 shows the ep indicator values for the assessment of irrigation performance monthly. The values of the ep indicator for section 2 (7.55), 1 (3.57) in March were very high. This should have been due to the water amount provided from the source was less than the amount needed. In the months studied, the highest ep values for all sections were for March and September. The values of ep were beyond the big value for all sections excluding for some sections in May and July as it is at the target value (1). That indicates that generally, monthly irrigation water requirements were not found in any other section. Seasonal values of the ep indicator are indicated in Table 7. The average seasonal ep indicator for the most sections was down the target value of (1). It is a clear indicator of sufficiency of water for the many sections. This might be affected by the point that the section nearby to the AL-Hindiyah barrage water source, therefore, it could easily obtain water. Section 2 was the section with the ep value (7.55) that was farthest and highest from the target and that had the poorest performance. During low ratios periods, the fraction of the water which is non-consumed would rises the groundwater table if that water used to the field (Bos *et al*., 1994) whereas during periods of a ratio >1 and to avoid water shortage, groundwater should be pumped and stored. The ep indicators differ among months because of difference in the volumes of the water obtained and the monthly water requirements.

Relative Water Supply (RWS): Irrigation manager could be award if enough water is being delivered to a big area of cropped land in order to come across the total crop water required by relative water supply. ep and RWS have a reversely relationship (Bastiaanssen *et al*., 2001). Table 6 indicates the monthly values of RWS. It is clear that all of the sections received a high water supply problem during March and September whereas in May and July there was an oversupply. The highest values of RWS were detected in May. The supply ratio to request for these nine sections was highest in July, yet the highest water requirement for all of the sections has been detected in July as shown in Table 2. Due to a little rain in May and none in July, irrigation meets all water requirements. RWS seasonal values are shown in Table 7. Assessment by season shows that the performances of section 5 (7.13) and 4 (4.68) were best and section 2 (0.40) was worst. It may be said that section 5 and section 4 were taking advantage of nearness to the source. It could be clear that there is an important variance among monthly indicators of RWS for all sections in the area of our research, indicating a month-to-month imbalance in water amount supplied for the irrigation system.

Depleted Fraction (DF): A value of DF (0.6) suggests that when ET_a is lower than 0.6 (Pg+VC), some of the offered water drives into storage, rising the groundwater table, whereas if ET_a is higher than 0.6 (P_g+V_C) storage will decrease (Bastiaanssen *et al*., 2001). The DF indicator monthly values for irrigation performance assessment are shown in Table 6. In this study, the DF averages values for all sections were normally less than the critical value (0.6), revealing that supplied water was more than was used up. The monthly DF values for many sections in

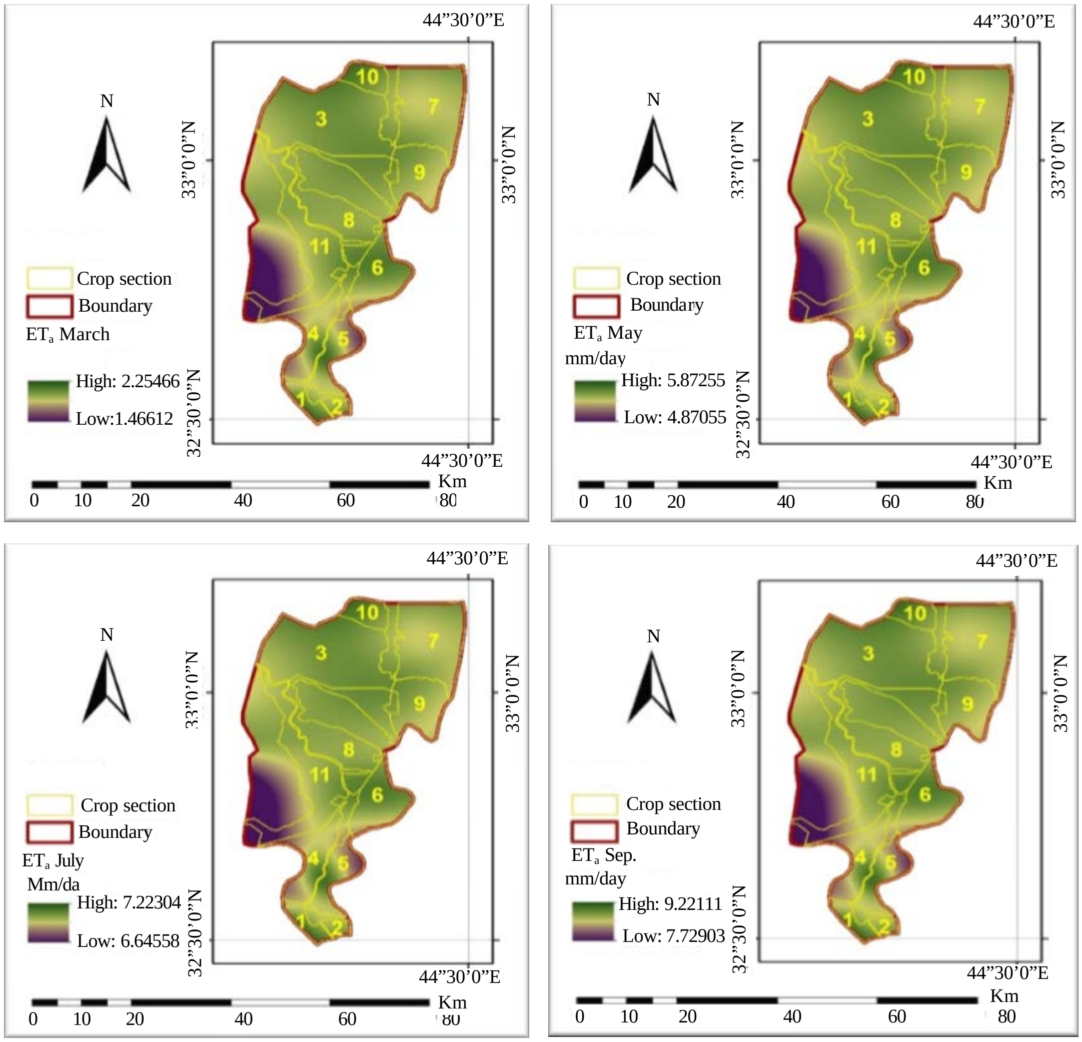

Fig. 2: Daily actual Evapotranspiration ET_a maps from SEBAL Model

selected months were low. These data tells that a big quantity of water supplied in these months from the source might not be used up by the plants that could clarify the less irrigation efficiency. Later, after the discussion with the managers, it is supposed that operating problems of the irrigation system (unscheduled irrigation, not irrigating at night, etc.) or physical problems (reversed slope, collapse, cracks) might play a significant role. Table 7 shows the seasonal average of DF indicators. The performance of sections 4 and 5 were below. All other sections performances were within standard limits. According to other performance indicators determination, it could be derive from the pricing policy of the irrigation water and the nearness of sections 4 and 5 to the source, AL-Hindiyah barrage which allowed them to get much more water during the season. The study could not differentiate between crops and the seasonal value of this section was 0.29, presenting that there was no enough groundwater supply and show the low irrigation effectiveness.

Crop Water Deficit (CWD): Table 6 presented the monthly values of the indicator of CWD. CWD values were more than the permissible levels (30 mm $month^{-1}$) for all sections in all months (March, May, July and September). Table 7 shows the seasonal entire values of the indicators of CWD. All sections exhibited a seasonal average CWD more than the permitted limits. This study shows that the seasonal average CWD indicators were higher in all sections.

Relative Evapotranspiration (RET): Table 6 indicated the monthly values of the indicator of RET. In March, RET values for all sections were the lowest as little amount or

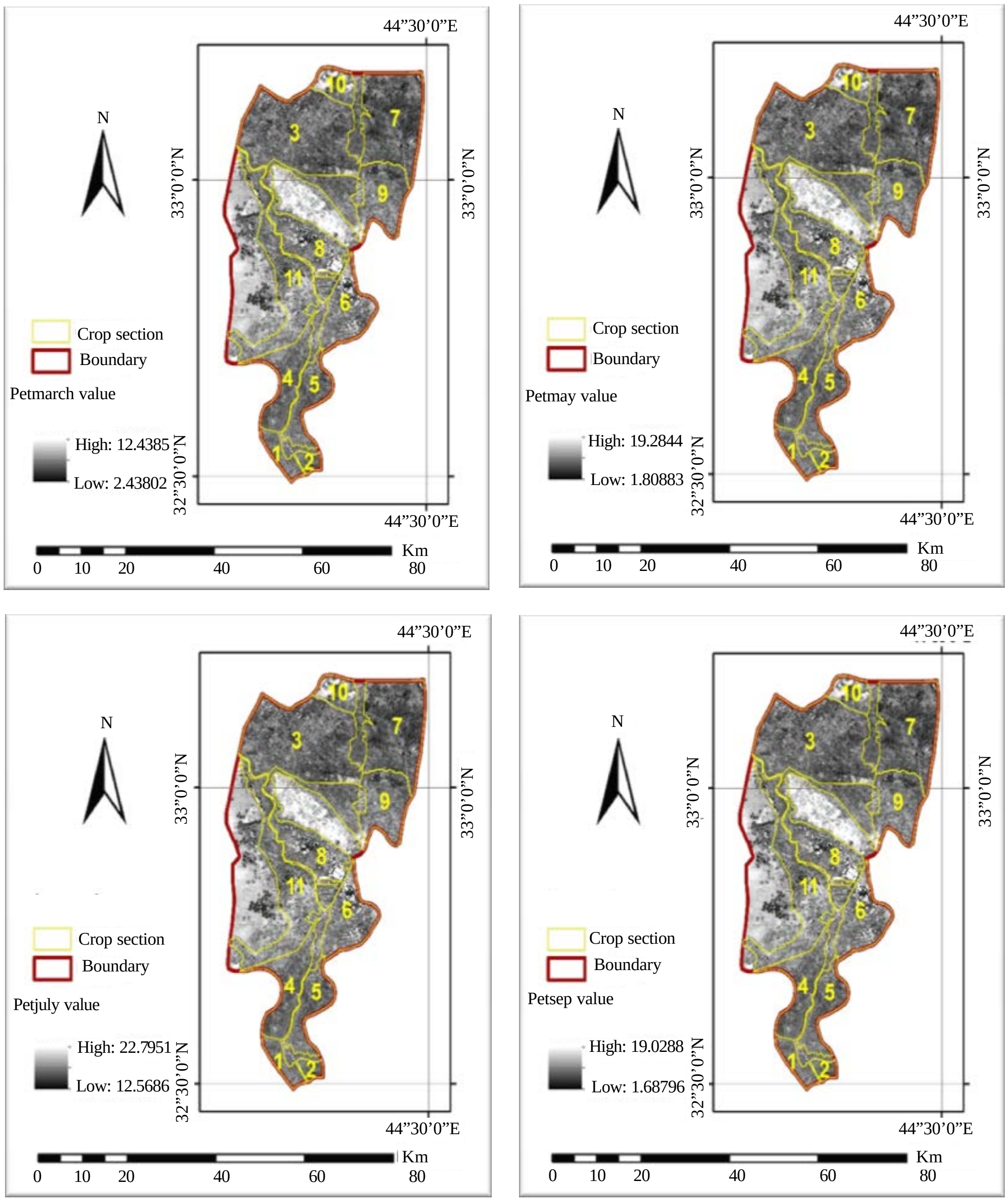

Fig. 3: Daily potential Evapotranspiration (ET_p) maps calculated from Penman-Monteith equation

no water was provided. From this result, it could be clear that when there is no rain or less rain, groundwater stored in the crop root area from appears to indicate the conclusion that high values of DF might feed to irrigation or rain in earlier times could have been used. Seasonally, RET does not achieve the suggested value of irrigated agricultural land (0.75) as shown in Table 7. Therefore, the seasonal RET performance was generally poor for all sections. The use of remote sensing in previous study showed that the RET average value in the Nilo Coelho irrigation system in Brazil was 0.77 (Bastiaanssen *et al*., 2001). In our study, The RET averages of the sections were lower and therefore we can say that they encountered a bigger problem with the water supply.

Table 6: Results of monthly performance assessment indicators

	March					May					July					Sep.				
Sections	ep	RWS	DF	CWD	RET	ep	RWS	DF	CWD	RET	ep	RWS	DF	CWD	RET	ep	RWS	DF	CWD	RET
1	3.57	0.38	0.65	192.17	0.25	0.86	1.16	0.35	234.76	0.41	0.93	1.08	0.38	300.17	0.41	2.58	0.39	1.74	120.33	0.68
2	7.55	0.25	1.03	185.29	0.26	1.88	0.56	0.73	234.27	0.41	2.03	0.49	0.83	305.23	0.41	5.59	0.18	3.75	118.89	0.68
3	1.48	0.75	0.34	187.40	0.26	0.36	2.68	0.15	233.46	0.41	0.39	2.57	0.16	296.70	0.42	1.08	0.96	0.73	118.38	0.68
4	0.54	1.84	0.15	177.04	0.27	0.15	6.63	0.06	256.18	0.39	0.16	6.20	0.06	344.84	0.38	0.44	2025	0.28	151.26	0.62
5	0.37	2.60	0.10	184.76	0.26	0.09	10.34	0.04	238.11	0.40	0.11	9.39	0.04	337.31	0.38	0.29	3.49	0.18	136.92	0.64
6	1.13	0.94	0.26	195.73	0.25	0.26	3.67	0.11	228.78	0.41	0.29	3.42	0.12	307.21	0.41	0.78	1.28	0.53	112.62	0.69
7	1.14	0.93	0.27	188.57	0.26	0.27	3.58	0.12	219.73	0.43	0.29	3.42	0.13	283.28	0.43	0.82	1.22	0.57	111.45	0.69
8	0.61	1.63	0.15	191.33	0.25	0.15	6.60	0.06	228.25	0.41	0.16	6.08	0.07	314.74	0.40	0.44	2.29	0.30	116.16	0.68
9	1.10	0.96	0.26	193.41	0.25	0.27	3.54	0.11	251.84	0.39	0.31	0.321	0.12	352.28	0.37	0.84	1.19	0.52	147.69	0.63
10	2.94	0.43	0.55	209.22	0.23	0.72	1.38	0.27	272.30	0.37	0.78	1.29	0.29	354.14	0.37	2.11	0.47	1.29	154.23	0.61
11	0.66	1.53	0.16	199.98	0.24	0.16	6.14	0.06	243.78	0.40	0.17	5.77	0.07	324.38	0.39	0.48	2.09	0.31	136.74	0.64

Table 7: Results of seasonal performance assessment indicators

						Performance indicators				
Sections	V_C	P_g	P_e	ET_p	ET_a	ep	RWS	DF	CWD	RET
1	299.89	13.77	10.27	384.18	172.321	1.247	0.816	0.549	211.855	0.449
2	137.86	13.55	10.09	382.88	171.963	2.704	0.395	1.136	210.917	0.449
3	710.05	13.70	10.22	381.03	172.043	0.522	1.899	0.238	208.984	0.452
4	1,878.04	12.70	9.34	403.63	171.300	0.210	4.684	0.091	232.332	0.424
5	2,800.69	12.87	9.49	394.69	170.417	0.138	7.129	0.061	224.275	0.432
6	963.35	13.62	10.14	381.65	170.559	0.386	2.560	0.175	211.086	0.447
7	924.85	13.81	10.31	374.55	173.793	0.394	2.506	0.185	200.757	0.464
8	1,739.40	13.77	10.27	383.16	170.538	0.214	4.576	0.097	212.622	0.445
9	984.91	13.28	9.84	407.16	170.848	0.403	2.452	0.171	236.306	0.420
10	394.52	12.49	9.15	417.35	169.876	1.035	0.975	0.417	247.474	0.407
11	1,679.65	13.85	10.34	396.47	170.248	0.230	4.271	0.101	226.222	0.429

CONCLUSION

The indicators of the irrigation performance provided data on the working of the eleven sections in the AL-Hindiyah barrage. Remote sensing offers chances to save new performance indicators like overall depleted fraction, consumed ratio, relative water supply, relative evapotranspiration and crop water deficit. The irrigation performance was generally poor for all of the sections, if it was taken on a seasonal or monthly basis. According to the inconsistency of the monthly values of performance indicators, viewing that good planning could not be done, or that, due to shortages at the source, irrigation was not homogeneous between the months. When irrigation was most intensive (May and July), the performance differs from when it was not intensive (March and September). Water source inefficiency is the main factor of this poor performance. The water was rerouted to the system in July and May when irrigation was intensive due to the insufficiency of the water source but could not be provided in enough amounts in other months. In some sections, there was a direct relationship between the amount of water obtained and nearness to the water source. Therefore, it is an advantage for the sections in obtaining water to be near to the source. Similarly, that a little quantity of the water provided from the source could be used is an indicator of low efficiency of irrigation. To increase the performance, there should be a concurrence between the period when water is provided from the source and the period when it is needed. Likewise, water delivery to the sections should be done with due consideration of water requirements expected in the overall irrigation plan.

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