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Irrigation Water Management Modeling in Canal Command Using Remote Sensing

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Abstract: Irrigation optimization is an important practice used in crop management, which could reduce irrigation water losses and maintain high yield in the canal command. Estimation of crop water demand based on temporal and spatial distribution is a prime requirement for efficient water management. Remote sensing based surface energy balance algorithm for land (SEBAL) has a good performance in both efficiency and applicability in evapotranspiration (ET) estimation. The crop water requirement was estimated using FAO-56 and SEBAL methods for the performance assessment of Ozat-II canal command area of Junagadh district, Gujarat, India. The irrigation efficiencies for the Ozat-II scheme were found out very low as 28.22% and 30.68% based on crop evapotranspiration (ET_c) FAO-56 method and SEBAL based actual evapotranspiration (AET) respectively for year 2014. The relative water supply (RWS) estimated from crop demands based on ET_c (FAO-56) and AET (SEBAL) were 1.28 and 1.17 respectively for year 2014. Whereas in year 2015, the RWS estimated from crop demands based on ET_c (FAO-56) and AET (SEBAL) were 0.83 and 0.92, respectively. The over irrigation was observed in year 2014 and deficit irrigation in year 2015. More area under higher values of NDVI were found in head end zone as comparison to that of middle zone and tail end zone of study area. The water productivity of summer groundnut crop was found lower as 0.103 kg m^{-3} using actual irrigation water supplied (WS). The water productivity was found out as higher 0.438 kg m^{-3} as per the AET (SEBAL). The water use efficiency (WUE) of summer groundnut and sesame crop were lower as 1.03 kg ha^{-1} mm^{-1} and 0.707 kg ha^{-1} mm^{-1}, respectively using WS. The maximum WUE of summer groundnut was found as 4.381 kg ha^{-1} mm^{-1} as per ET_c (FAO-56) and 2.931 kg ha^{-1} mm^{-1} of summer sesame using AET (SEBAL). The results indicates that there is a significant scope to increase land and water productivity in Ozat-II canal command by adopting crop water requirement estimation based on remote sensing.

Key words: Canal command, evapotranspiration, remote sensing, performance indicators, water use efficiency.

The total water demands are increasing rapidly and due to that, the water for agriculture is getting limited. Efficient water use for agriculture is very low in India and there is an imminent need to improve it. Irrigation is mainly dependent on various sources, including the availability of canal water and ground water. Water use efficiencies are comparatively less in canal command areas than command areas that depend on groundwater. In India, most of the prominent canal command areas suffer from either excessive or inadequate water supply resulting in wide gap between irrigation demand and supply. Generally, under open canal conveyance and surface irrigation methods less than half of the water-released reaches the field. The majority of irrigation projects in India perform at a low overall efficiency of 30% (Sarma and Rao, 1997), which provides an opportunity for meeting the increasing water demands by adopting efficient methods of water management. The National Commission on Integrated Water Resources Development (NCIWRD, 1999) has projected that India's surface irrigation systems will work at 40, 50 and 60% efficiency levels in 2010, 2025 and 2050, respectively. The NCIWRD estimated the overall efficiency for surface water system from 30 to 65% and overall efficiency for ground water system from 65 to 75% (CWC, 2014). Another significant problem that is expected in the future is the increasing need for alternative demands for water supply due to urbanization

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and industrialization. These demands create more pressure on water resources and in turn on irrigation sector. Therefore, irrigation in the future will certainly face the challenge of maximizing efficiency. Hence, in order to enhance the irrigation efficiency, estimation of irrigation demand is really important coupled with efficient management of water in the canal command area before releasing the water to the crops.

Crop evapotranspiration represents the crop water demand and governed by weather and crop conditions and most of the current water demand models are a non-spatial model, which uses point data of reference evapotranspiration and the crop coefficient values from available literature (Doorenbos and Pruitt, 1977). The Food and Agriculture Organization (FAO) Penman-Monteith (Allen *et al.*, 1998) empirical calculation uses standard meteorological data to estimate the evapotranspiration (ET) of a reference crop, which is in turn modified by a crop factor to estimate the ET of a particular crop.

The remote sensing technique is helpful in the collection of spatial and temporal information of the land surface from larger geographic area, provides an effective tool and methodology for retrieving the ground parameters for estimating evapotranspiration at regional scale. The Surface Energy Balance Algorithm for Land (SEBAL) is a model with strong physical basis and less requirement of concurrent ground level observations. It is the energy balance algorithms developed for estimating actual evapotranspiration based on remotely sensed data (Bastiaanssen *et al.*, 1998a; 1998b). It calculates evapotranspiration through different computational sub-models that generate net surface radiation, soil heat flux and sensible heat flux to the air. The relationships between visible and thermal infrared spectral radiances of areas with a sufficiently large hydrological contrast constitute the basis for the formulation of the SEBAL model. After its first derivation for Egypt, Spain and Niger, SEBAL has been successfully applied to different ecosystems in more than 30 countries (Bastiaanssen *et al.*, 2005). Studies (Bastiaanssen *et al.*, 2010; Morse *et al.*, 2000) showed that errors of seasonal ET determined by SEBAL were within 5% of other accepted ET measurement methods, while errors of daily ET were less than 15%, which suggests that SEBAL has a good performance in both efficiency and applicability in ET estimation. In the present research work, the crop water requirement was estimated using FAO-56 method and actual evapotranspiration was estimated using SEBAL methodology to assess the performance of the canal irrigation system in semi-arid region.

Materials and Methods

Study area

The study area comprises the canal command area of Ozat-II dam across river Ozat near Badalpur, Junagadh district, Gujarat, India. The gross and live storage capacity of the reservoir is 36.20 MCM and 27.71 MCM, respectively. The location of the command area lies between latitude 21°12′46″N to 21°33′04″N and longitude 70°25′07″E to 70°53′24″E. The canal system comprises of 20.60 km long main canal (Fig.1).

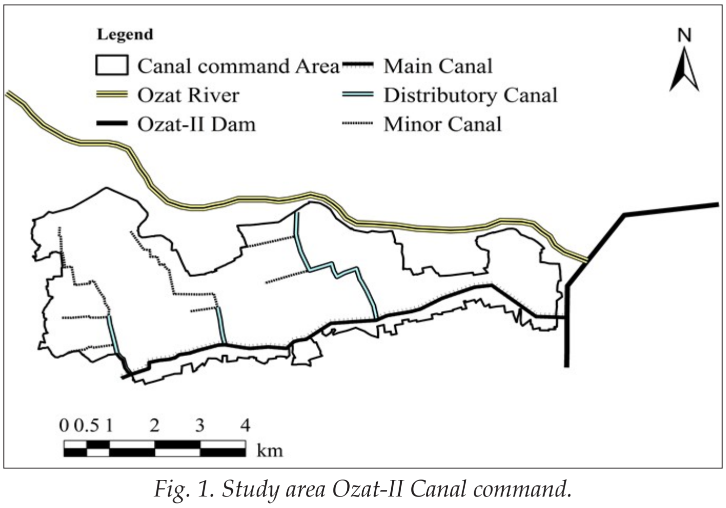

Fig. 1. Study area Ozat-II Canal command.

Climate of study area

The climate of study area is subtropical and semi-arid type which receives rainfall from south-west monsoon. The mean rainy days during monsoon seasons are 35.8 and mean annual rainfall is 857.9 mm with standard deviation of 365.5 mm for last 31 years (1985-2015). The maximum annual rainfall recorded was 1430.5 mm in year 2013. January is the coldest month with mean monthly temperature varying from 7°C to 15°C. The average number of cold days (≤10°C) during winter season are 19 days with 9.58 standard deviation. The maximum monthly temperature was recorded in the month of May varying between 29.50°C to 39.40°C. The average number of hot days (≥ 40°C) during summer season were 24.52, with 8.92 standard deviation. The weekly average maximum temperature of 50 years (1965-2014) was 34.19°C and varying between 29.40°C and 39.40°C, whereas the weekly average minimum temperature was 19.99°C and varying between 10.10°C and 26.70°C. The weekly average relative humidity of 50 years (1965-2014) was 66.12% and varying between 50% and 88% (Fig. 2). The weekly average wind speed was 7.7 km h^{-1} and varying between 4.10 to 13.30 km h^{-1}. The weekly normal bright sunshine hours were 7.6 h and varying between 2.0 to 10.1 h. The weekly average evaporation was 6.7 mm and varying between 3.5 to 10.6 mm.

Data and software used

The daily climatic data were collected from the Agrometeorology Cell, JAU, Junagadh. The data includes daily maximum air temperature, minimum air temperature, maximum relative humidity, minimum relative humidity, wind speed, actual sunshine hours, pan evaporation, radiation, maximum soil temperature, minimum soil temperature, etc. The Landsat-7 ETM+ and Landsat-8 OLI/TIRS images were downloaded from USGS Earth Explorer www.earthexplorer.usgs.gov/for different dates of pass (Day of year: DOY) as 25/03/2014 (084), 02/04/2014 (092), 18/04/2014 (108), 26/04/2014 (116), 12/05/2014 (132) and 20/05/2014 (140) for year 2014. Total 5 Landsat-8 OLI/TIRS images were used for the dates of pass (DOY) of year 2015 as 28/03/2015 (087), 13/04/2015 (103), 29/04/2015 (119), 15/05/2015 (135) and 31/05/2015 (151) for summer season, which represented different growth stages of the summer crop. Different softwares like Geomatica 10.0, ArcGIS 10.3, GRASS GIS 7.0.1 and QGIS 2.10.1 were used for different remote sensing and GIS operations. The primary and secondary data were collected and verified with the ground truth data.

Estimation of crop evapotranspiration using FAO-56 approach

Crop evapotranspiration under standard conditions (ET_c) is the evapotranspiration from the disease-free, well-fertilized crops, grown in the large fields, under optimum soil water conditions and achieving full production under the given climatic conditions. The effects of various weather conditions on evaporation are incorporated into crop ET_0; the effects of characteristics that distinguish the cropped surface from the reference surface are integrated into the crop coefficient K_c. By multiplying ET_0 with the crop coefficient, ET_c is determined as

$$ET_c = K_c \times ET_0 \qquad (1)$$

Reference crop evapotranspiration (ET_0)

The evapotranspiration rate from a reference surface, without water stress, is called the

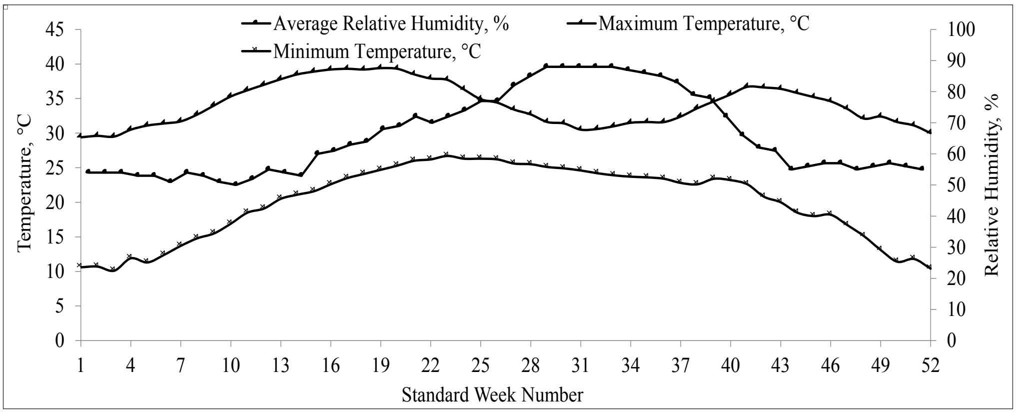

Fig. 2. The weekly average maximum, minimum temperature and relative humidity of 50 years (Year: 1965-2014).

reference crop evapotranspiration and is denoted as ET_0. The FAO Penman-Monteith method is now recommended as the sole standard method for the definition and computation of the reference evapotranspiration, Allen *et al.* (1998). The reference evapotranspiration (ET_0) can be estimated using FAO Penman-Monteith method, the equation is given as,

$$ET_0 = \frac{0.408\Delta(R_n - G) + \frac{\gamma(900)}{T+273}u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \tag{2}$$

where,

ET_0 = Reference evapotranspiration (mm d^{-1})
R_n = Net radiation at the crop surface (MJ m^{-2} d),
G = Soil heat flux density (MJ m^{-2} d),
T = Mean daily temperature at 2 m height (°C),
e_s = Saturation vapor pressure at T_c (kPa),
e_a = actual vapor pressure (kPa),
e_s - e_a = saturation vapor pressure deficit (kPa),
Δ = slope of the e_s, temperature relationship (kPa/°C),
γ = psychrometric constant (kPa/°C) and
u_2 = wind speed at 2 m height (m/s)

FAO-56 crop coefficients correction for local climatic conditions

The FAO-56 Table 12 (Allen *et al.*, 1998), contains the typical values for crop coefficients (K_c) of various crops for initial, mid-season and late season of crop growth stages. The tabulated values of FAO-56 crop coefficients were corrected for local climatic conditions using local climatic and soil parameters using standard formula.

$$K_{c\,ini} = K_{c\,ini(Fig.29)} + \frac{(I-10)}{(40-10)}\left[K_{c\,ini(Fig.30)} - K_{c\,ini(Fig.29)}\right] \tag{3}$$

$$K_{c\,mid} = K_{c\,mid(tab)} + [0.04(u_2 - 2) - 0.004(RH_{\min} - 45)](\frac{h}{3})^{0.3} \tag{4}$$

$$K_{c\,end} = K_{c\,end(tab)} + [0.04(u_2 - 2) - 0.004(RH_{\min} - 45)](\frac{h}{3})^{0.3} \tag{5}$$

where, $K_{c\ ini}$ is the K_c value for initial stage of crop, $K_{c\ ini\ (Fig.\ 29)}$ and $K_{c\ ini\ (Fig.\ 30)}$ are the values for K_{cini} from Fig. 29 and Fig. 30 of FAO-56 respectively, I is average infiltration depth in mm. $K_{c\ mid\ (tab)}$ = the tabulated value of $K_{c\ mid}$ in Table 12 of FAO 56, u_2 is the mean value for daily wind speed at 2 m height over grass during the mid-season growth stage (ms^{-1}), RH_{min} is the mean value for daily minimum relative humidity during the mid-season growth stage (%), h is mean plant height during the mid-season stage (m). $K_{c\ end}$ (tab) is the value for $K_{c\ end}$ in Table 12 of FAO 56.

Estimation of crop evapotranspiration using remote sensing

SEBAL uses a set of algorithms to solve the energy balance at the earth's surface. The three primary bio-physical inputs from Landsat images into SEBAL are (i) surface temperature, (ii) surface albedo and (iii) Normalized Difference Vegetation Index (NDVI). The instantaneous ET flux is calculated for each pixel within a remotely sensed image as a 'residual' of the surface energy budget equation:

$$\lambda ET = R_n - G - H \tag{6}$$

where,

λET = Latent heat flux (W m^{-2}) (which can be equated to ET)
R_n = Net radiation flux at the surface (W m^{-2})
G = Soil heat flux (W m^{-2})
H = Sensible heat flux to the air (W m^{-2})

Soil heat flux (G)

There are two types of transport processes in the soil; conduction and convection. Soil heat flux through a porous medium includes heat transport through each soil component: water, air, minerals and organic matter. Bastiaanssen (2000) proposed G as an empirical fraction of the net radiation using surface temperature, surface Albedo (α) and NDVI and was adopted in this study to compute G as:

$$G = R_n\left(\frac{T_s}{\alpha}\right) \times \left(0.0038\alpha + 0.0074\alpha^2\right) \times \left(1 - 0.98NDVI^4\right) \tag{7}$$

Sensible heat flux (H)

The sensible heat flux (H) is the energy which is directly transferred to the air via convection. The sensible heat flux is the flow of energy through air as a result of the temperature gradient (dT). During the SEBAL process, dT can be calculated at two extreme "indicator" pixels (endpoints) by assuming values for H at the reference pixels. The reference pixels are carefully chosen so that, at these pixels it can assume that, H = 0 at a very wet pixel (i.e., all available energy (R_n - G) is converted to

ET) and that $\lambda(ET_{ins}) = 0$ at a very dry pixel, so that $H = R_n - G$. The sensible heat flux (H) was calculated as;

$$H = \frac{\rho_a C_p dT}{r_{ah}} \tag{8}$$

where,

ρ_a = Air density (kg m^{-3}) which is a function of atmospheric pressure

C_p = Heat capacity of air (1004 J kg^{-1} K)

r_{ah} = Aerodynamic resistance to heat transport (S m^{-1})

dT = Temperature difference (T_o - T_a)

Evaporative fraction

Evaporation from the surface over land usually displays a pronounced diurnal variation. The evaporative fraction (EF) at each pixel of the image, one can estimate the 24-hour evapotranspiration for the day of the image by assuming that the value for the EF is constant over the full 24-hour period. The evaporative fraction (Brutsaert and Sugita, 1992) is the energy used for the evaporation process divided by the total amount of energy available for the evaporation process. The EF was calculated for the instantaneous values in the image as:

$$EF = \frac{(R_n - G - H)}{R_n - G} \tag{9}$$

Daily actual evapotranspiration estimation

The twenty-four Hour actual evapotranspiration estimation ($ET_{24,}$ mm d^{-1}) was estimated by the following equation:

$$ET_{24} = \frac{86400\ EF\ (R_{n24} - G)}{\ddot{e}} \tag{10}$$

where,

R_{n24} = Daily net radiation, W/m^2

EF = Evaporative fraction

λ = Latent heat of vaporization (2.47 x 10^6 J kg^{-1})

Irrigation performance indicators

The canal command irrigation system was evaluated using performance indicators like the adequacy, equity and agricultural productivity of the irrigated agriculture system.

Adequacy

The adequacy indicator gives information about the quantity of water provided sufficient for the growth needs of the crops. The relative water supply (RWS) defined by Levin (1982) describes the adequacy of water supply. RWS was computed by the following expression:

$$RWS = \frac{IR + RN}{GIR} \tag{11}$$

where,

IR = Irrigation water released from canal, m^3

RN = Rainfall, m^3

GIR = Gross irrigation requirement, m^3

The major rainfall season, for this region, is June to November, with nil rainfall at February to May (summer season), which can be neglected. The gross irrigation requirement is computed from the net irrigation requirement (IR_{Net}) divided by irrigation efficiency (accounting for losses during conveyance, distribution and application). Net irrigation requirement (IR_{Net}) is computed using following expression:

$$IR_{Net} = ET_c - ER + WSP + AL \tag{12}$$

where,

ET_c = Actual crop evapotranspiration, m^3

ER = Effective rainfall, m^3

WSP = Water for special purposes, including land preparation, transplantation, etc., m^3

AL = Application losses in the fields, including percolation, seepage, runoff, etc., m^3

For irrigation commands where these data are not available, Ray *et al.* (2002) suggested to adopt an adjustment factor to account for various components of above equations.

Equity

Levin and Coward Jr. (1989) have suggested that a system that is considered fair by most farmers is more efficient than the one that the water authority has designed on the basis of productivity and efficiency but which is considered unfair by the farmers. Any irrigation distribution system, which practices equity in water allocation and distribution, will have uniformity in the cropped area and crop vigor along the distribution system. Rouse *et al.* (1974) proposed normalized difference vegetation index (NDVI) by considering the high reflectance of vegetation in the NIR region as compared to Red. The NDVI is a measure of the amount and vigor of vegetation at the surface. It can be calculated as:

$$NDVI = \frac{NIR - R}{NIR + R} \tag{13}$$

where,

NIR = Reflectance in the near-infrared band (Band 5 for Landsat-8 OLI/TIRS and Band 4 for Landsat-7 ETM + image)

R = Reflectance in the red visible band (Band 4 for Landsat-8 OLI/TIRS and Band 3 for Landsat-7 ETM + image)

Agricultural productivity

Agricultural production performance indicators include cropping intensity, ratio of area planted and area harvested, annual yield, productivity of land, and productivity of water (Rao, 1993). In the present study, an attempt has been made to estimate the productivity of water using remote sensing data. Productivity of water or water use efficiency (WUE) can be expressed as:

$$WUE = \frac{Y_{act}}{WS} \tag{14}$$

where,

Y_{act} = Actual crop yield

WS = Total water supplied

Results and Discussion

Crop evapotranspiration

The daily reference evapotranspiration (ET_0) was estimated using the FAO-56 Penman-Monteith for summer season of year 2014 and 2015 (Fig. 3). The daily reference evapotranspiration was increased from 30th day of year (DOY) to 151st DOY. The maximum daily reference evapotranspiration was estimated as 7.87 mm d^{-1} and 8.26 mm d^{-1} for year 2014 and 2015, respectively. Similarly, the minimum daily reference evapotranspiration was estimated as 3.12 mm d^{-1} and 2.98 mm d^{-1} for year 2014 and 2015, respectively.

The daily average crop evapotranspiration for the initial stage, growth stage, mid stage and end stage of summer groundnut crop were estimates as 3.24, 6.01, 8.15 and 3.97 mm d^{-1}, respectively. The maximum daily average crop evapotranspiration value was estimated as 8.15 mm d^{-1} for the mid-crop stage. Similarly, the daily average crop evapotranspiration for the initial stage, growth stage, mid stage and end stage of sesame crop were estimates as 3.75, 5.52, 8.12 and 1.83 mm d^{-1}, respectively. The maximum daily average crop evapotranspiration value was estimated as 8.12 mm d^{-1} for the mid-crop stage.

The SEBAL parameters were estimated using different bands of Landsat 7 and Landsat 8 images of year 2014 and 2015 to determine the actual evapotranspiration of the Ozat-II canal command area. The digital images of band number 1, 2, 3, 4, 5 and 7 of Landsat-7 and band number 1, 2, 3, 4, 5, 6, 7, 8 and 9 of Landsat-8 were converted into reflectance and radiation. The images were radiometrically and atmospherically corrected using the GRASS GIS 7.0.1 software. Initially the Digital Number (DN) values were converted into top of atmosphere

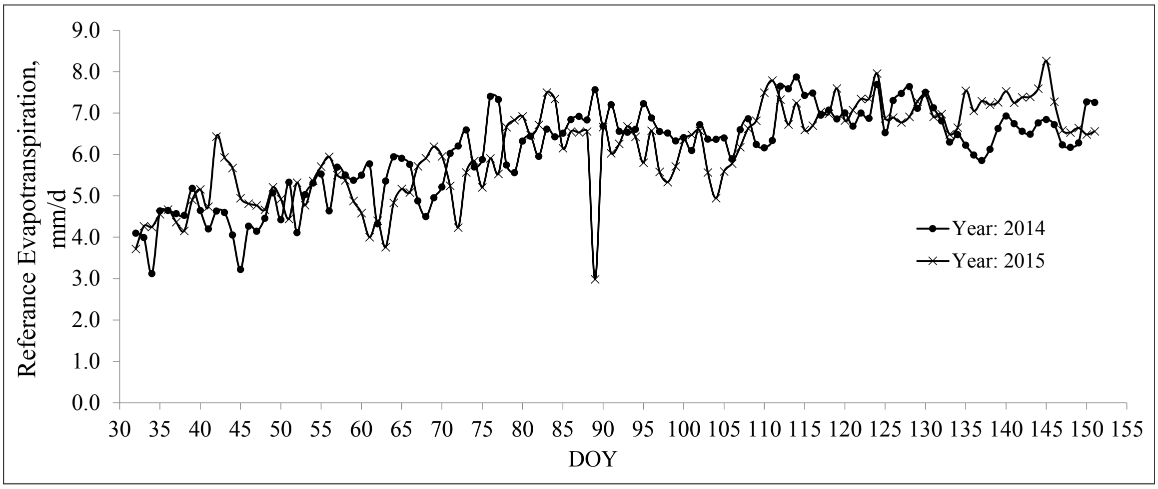

Fig. 3. Daily reference evapotranspiration for different DOY.

(TOA) reflectance and radiation for Landsat images using band-specific multiplicative rescaling factors from the metadata files. The reflectance were corrected using the sun elevation angle of respective bands. The band 6.1 and 6.2 of Landsat-7 and band 10 and 11 of Landsat-8 were converted into temperature using thermal constant of respective bands provided into the metadata file of each images.

The atmospheric and radiometric corrected Landsat were used to estimate the Normalized Difference Vegetation Index (NDVI), Soil Adjusted Vegetation Index (SAVI), albedo, emissivity etc. for different dates of pass (DOY) for year 2014 and 2015. The instantaneous R_n (W m^{-2}) was evaluated in terms of its components of downward and upward shortwave radiation fluxes and downward and upward long-wave radiation fluxes. The soil heat fluxes for different dates for the study area were estimated using the albedo, surface temperature, NDVI and net radiation. The relationship between the day time ratio of G/R_n and NDVI were developed for different dates for the validity and applicability of soil heat flux equations. The good correlation coefficients between G/R_n and NDVI were observed for mid-stages of crop for both years. The estimated soil heat flux, sensible heat flux and evaporative fractions were used to estimate the actual evapotranspiration. The estimated daily actual evapotranspiration (AET) values in the canal command area were ranged from 3.75 mm d^{-1} to 7.377 mm d^{-1} and from 1.06 to 7.721 mm d^{-1} for year 2014 and 2015 respectively (Fig. 4).

Irrigation efficiency

The irrigation efficiency of Ozat-II canal command was calculated using the actual water applied and crop evapotranspiration values calculated using FAO-56 method and SEBAL method (Fig. 5). The irrigation efficiencies for the whole Ozat-II scheme were found out as 28.22% and 30.68% based on crop evapotranspiration FAO-56 method and SEBAL based crop evapotranspiration respectively for year 2014. The irrigation efficiencies for the whole Ozat-II scheme were found as 43.17% and 39.12% using FAO-56 based crop evapotranspiration and SEBAL based actual evapotranspiration respectively for year 2015. Bandara (2003) estimated three large irrigation systems in Sri Lanka and found the irrigation efficiencies as 48%, 71% and 32%. Perry *et al.* (2009) cited the work of Postel and Vickers (2004), showing the surface water irrigation efficiency between 25% and 40% in India, Mexico, Pakistan, the Philippines and Thailand; between 40% and 45% in Malaysia and Morocco; and between 50% and 60% in Israel, Japan and Taiwan. They also stated that the irrigation water efficiency is affected not only by the type and condition of irrigation systems, but also by soil type, temperature, humidity. In hot arid region, the evaporation of irrigation water is far higher than in cooler humid region.

Relative water supply (RWS)

The gross irrigation requirement (GIR) estimated from crop evapotranspiration demands (ET_c) values based on FAO-56 and

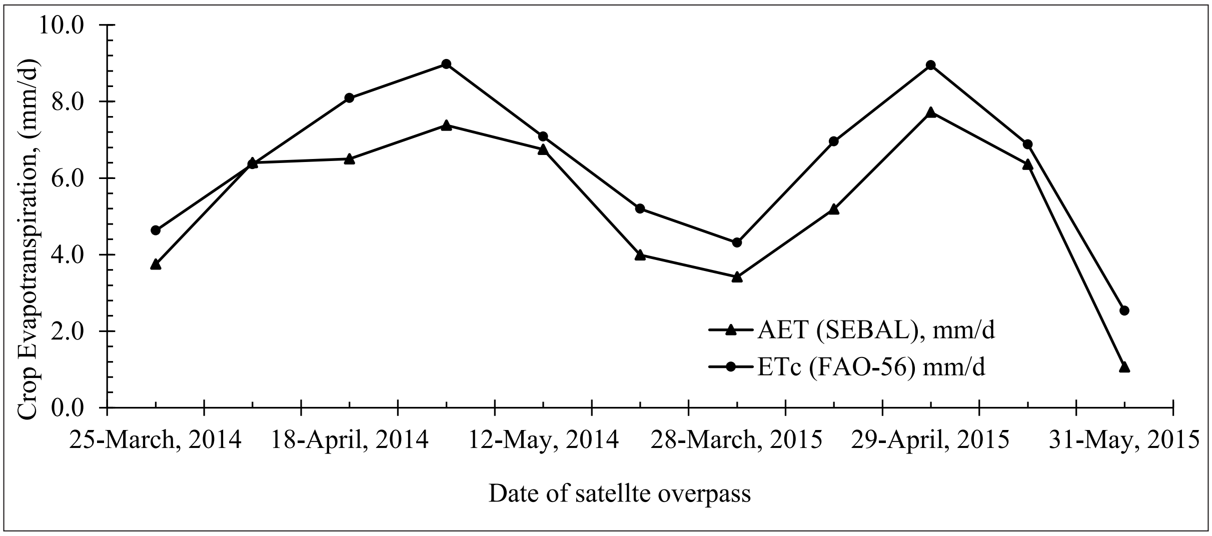

Fig. 4. The trend of actual evapotranspiration (SEBAL) and crop evapotranspiration (FAO-56) for year 2014 and 2015.

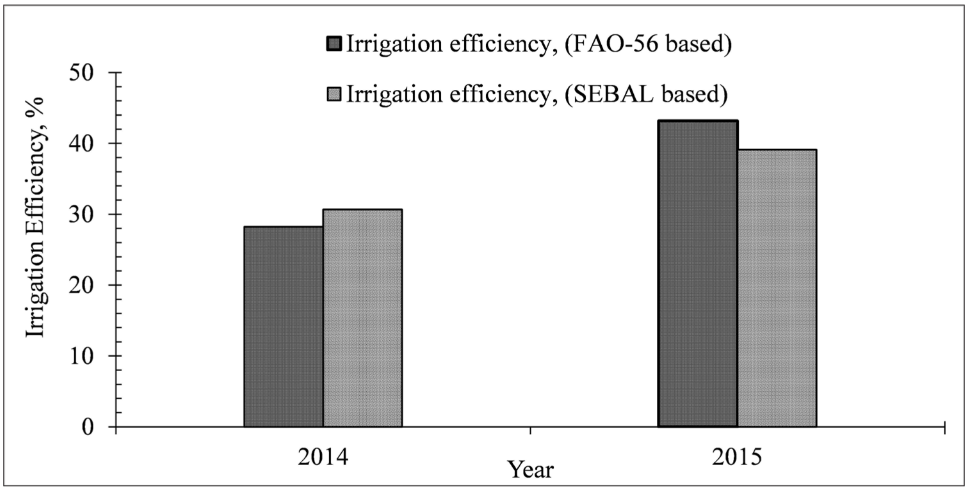

Fig. 5. Irrigation efficiency based on FAO-56 and SEBAL for summer crop season.

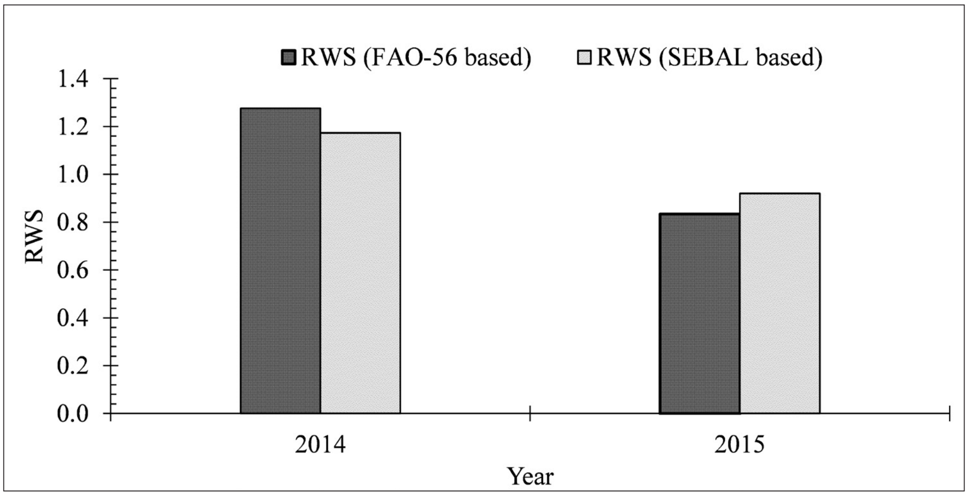

Fig. 6. Relative water supply (RWS) based on FAO-56 and SEBAL for summer crop season of year 2014 and 2015.

SEBAL methods. The relative water supply (RWS) estimated from crop demands based on ET_c (FAO-56) and AET (SEBAL) were 1.28 and 1.17, respectively for year 2014 (Fig. 6). Whereas in year 2015, the RWS estimated from crop demands based on ET_c (FAO-56) and AET (SEBAL) were 0.83 and 0.92, respectively (Fig. 6). The RWS falls in adequate water ($0.9 < RWS < 1.1$, Ray *et al.*, 2002) based on the AET (SEBAL) for year 2015. In addition, it can be seen that the values found in the present study using SEBAL were close to the value (1.08) given by Merdun and Degirmenci (2004) for the Menemen irrigation system as a whole for 2001, and much lower than the average value (2.66) that they gave for the 239 irrigation systems in Turkey for the same year.

The excess volume of water was released during year 2014 as 251.04 ha m and 171.78 ha m as per ET_c (FAO-56) and AET (SEBAL) respectively. During year 2015, less volume of water was released as 146.32 ha m and 63.619.89 ha.m as per ET_c (FAO-56) and AET (SEBAL) respectively for year 2015 (Table 1).

Table 1. Irrigation water released from canal (IR), gross irrigation requirement (GIR) and excess or deficit water supple based on FAO-56 and SEBAL for summer crop season

Year	Irrigation water released (IR), ha m	GIR ha m		Excess (+) or deficit (-), ha m	
		ET_c (FAO-56)	AET (SEBAL)	ET_c (FAO-56)	AET (SEBAL)
2014	1162.00	910.96	990.22	251.04	171.78
2015	734.72	881.04	798.33	-146.32	-63.61

Equity

The canal command area was bifurcated into three nearly equal zones from the head to tail. The difference in the area under crop, crop vigor in terms of NDVI between head and tail zones of main canal were studied. The area of head end zone, middle zone and tail end zone were 905.3 ha (31.15%), 994.8 ha (34.23%) and 1006.1 ha (34.62%) respectively. More area under higher values of NDVI were found in head end zone as comparison to that of middle zone and tail end zone of study area. The area under lower value of NDVI increased from head zone to tail zone. The area under vigor crop i.e. higher value of NDVI was increased from 61.97% of tail end zone area to 89.33% of head zone area. The maximum area under higher values of NDVI was under the head end zone canal command area. It was found that the crop vigor, as expressed by the NDVI values, was lower in zones towards the tail end as compared to the vigor crop in the area under head end zone.

Agricultural productivity/water use efficiency (WUE)

The estimated water productivity of summer groundnut crop was found lower as 0.103 kg m^{-3} using actual irrigation water supplied (WS), that was low (<0.3 kg m^{-3}) as per the categorization of water productivity by Cai *et al.* (2009). Similarly low value of water productivity 0.10 to 0.22 kg m^{-3} for groundnut crop was observed by Adeeb (2006) in Sudan and 0.09 to 0.36 kg m^{-3} were observed by Al Zayed *et al.* (2015) in the Gezira Scheme, Sudan. The water productivity was found out as higher (> 0.4 kg m^{-3}, Cai *et al.,* 2009) as 0.438 kg m^{-3} as per the AET (SEBAL). The water use efficiency (WUE, kg ha^{-1} mm^{-1}) or crop productivity for per unit water supplied in summer season for Ozat-II canal command were estimated using actual yield and actual irrigation water supplied (WS) as the actual irrigation water released (IR), $ET_{c\text{-FAO-56}}$ based water requirement and water requirement as per SEBAL based actual evapotranspiration (AET). The composite WUE was determined for entire command as the canal releases were available for whole command. The water use efficiencies of summer groundnut crop were ranged from 1.03 to 1.236 kg ha^{-1} mm^{-1} using the actual irrigation water delivered from the dam through canal and using the actual yield. The WUE for summer sesame crop was ranged from 0.707 to 1.147 kg ha^{-1} mm^{-1} using the using the actual irrigation water delivered from the dam through canal and using the actual yield (Fig. 7).

Accordingly, the productivity of summer groundnut of the Ozat-II canal command was in low level of water productivity. By considering the crop evapotranspiration estimated using FAO-56 and actual crop evapotranspiration estimated using SEBAL for summer groundnut crop, the WUE varies from 3.650 to 4.381 kg ha^{-1} mm^{-1} and from 3.358 to 4.030 kg ha^{-1} mm^{-1} respectively. Ibrahim *et al.* (2002) also estimated the water-use efficiency of groundnut as 0.35 kg m^{-3} in the Gezira Scheme, Sudan. In year 2015, using the crop evapotranspiration estimated using FAO-56

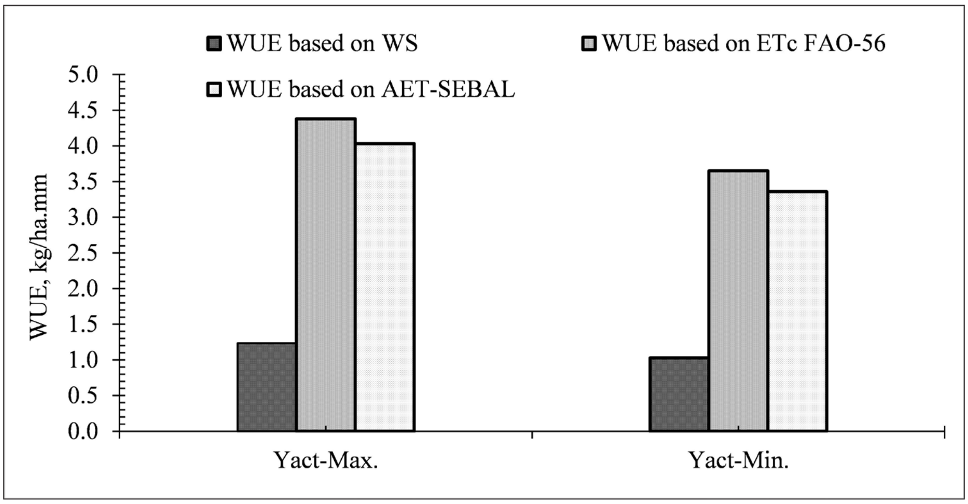

Fig. 7. WUE (kg ha^{-1} mm^{-1}) using actual WS, ETc FAO-56 and AET-SEBAL and actual yield (Y_{act}) of summer groundnut.

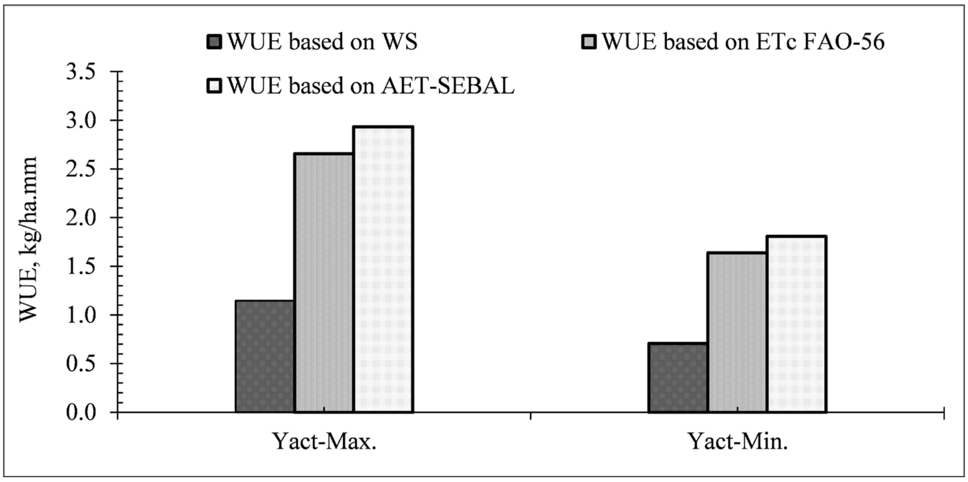

Fig. 8. WUE (kg ha^{-1} mm^{-1}) using actual WS, ETc FAO-56 and AET-SEBAL and actual yield (Y_{act}) of summer sesame.

and actual crop evapotranspiration estimated using SEBAL for summer sesame crop, the estimated values of WUE were ranged from 1.638 to 2.656 kg ha^{-1} mm^{-1} and from 1.808 to 2.931 kg ha^{-1} mm^{-1} respectively (Fig. 8). In general, water productivity in Ozat-II canal command showed low values compared to global averages retrieved from 44 publications from 22 countries in the world (Zwart and Bastiaanssen, 2004). These results indicate a highly significant scope to increase land and water productivity in Ozat-II canal command.

Conclusions

The irrigation performance indicators were estimated for Ozat-II canal command based on FAO-56 and SEBAL method using remote sensing. The estimation of different parameters of SEBAL using Landsat images gives the spatial-temporal information of crop evapotranspiration in canal command area. Remote sensing based crop water requirement helps in preformation evaluation of irrigation canal command. The lower irrigation efficiencies were observed in Ozat-II canal command area as per ET_c (FAO-56) and AET (SEBAL). The relative water supply was more during year 2014 as compared to 2015. The excess volume of water was released during year 2014 and deficit volume of water was released during year 2015. The more vigor crop, as expressed by the higher values of NDVI was found in the head end zone area as compared to that of in the tail end. There was large gaps in area under crop between head reach area and tail reach area. The water productivity of the Ozat-II canal command was in low level as calculated using the actual water released for irrigation from the dam. The water use efficiency was observed higher as per the ET_c (FAO-56) and AET (SEBAL) in comparison of actual water released. These results indicate a significant scope to increase land and water productivity in Ozat-II canal command by adopting the water requirement estimated using FAO-56 and SEBAL. The corrective management and application of water in subsequent seasons as per the remote sensing method will help in overall and equitable improvement in Ozat-II irrigation canal command.

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