Decision Support System for Estimating Actual crop Evapotranspiration using Remote Sensing, GIS and Hydrological Models

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Abstract:

Evapotranspiration (ET) is a major component of the hydrologic cycle and its accurate estimation is essential for hydrological studies. In the past, various estimation methods have been developed for different climatologically data, and the accuracy of these methods varies with climatic conditions. Therefore, **Remote** Sensing and GIS techniques with Hydrological Models are used to develop a friendly decision support system (DSS) for estimating of the Actual Crop ET. For given data availability and climatic conditions, the developed model estimates ET. The ET estimation methods are based on combination theory, radiation, temperature, and Remote Sensing methods; the model selects the best ET estimation method based on ASCE rankings. In order to evaluate the DSS, various tests were conducted with different data availability conditions for three climatological studies at the stations CAMA, NWRA, and Al-Irra. The decisions made by the model exactly matched the ASCE rankings. For the two climatic stations NWRA, and CAMA, ET values were estimated by all applicable methods using this models was developed for ERDAS Imagine and Arc-GIS software and were compared with the Penman-Monteith ET estimates, which were taken as the standard. Based on the weighted average standard error of the estimate, the modified SEBAL , and Biophysical model methods ranked first, respectively, for areas near the CAMA and NWRA stations. The $SEBAL_{ID}$ ranked first for Al-Irra station. The DSS model is developed as user tool for estimating ET under different data availability and climatic conditions.

Key Words: DSS, Yemen, ET, PET, Remote Sensing, SEBAL,GIS.

1. INTRODUCTION

Evapotranspiration (ET) constitutes an important component of the water fluxes of the hydrosphere and the atmosphere. An estimated 70 % of the water loss from the earth's surface occurs as evaporation. It is a process that results from complex interaction between water and energy fluxes subjected to changing atmospheric, soil and vegetation conditions. Accurate estimation of evapotranspiration ET is essential for many studies such as hydrologic water balance, irrigation scheduling, and water resources planning and management (Biju, et al, 2002).

The complex variations in climate, terrain features, and vegetative covers complicate our attempt to quantify the ET at a regional scale adequately (Moges, M.A, 2002). If this significant portion of the hydrologic cycle (which is, ET) is adequately estimated at regional or catchment scale, estimation of the catchment water yield can be enhanced. ET is a complex phenomenon because it depends on several climatological factors, such as temperature, humidity, wind speed, radiation, and type and growth stage of the crop. ET can be either directly measured using lysimeter or water balance approaches, or estimated indirectly using climatological data. However, it is not always possible to measure ET using a lysimeter because it is a time-consuming method and needs precise and carefully planned experiments. The indirect ET estimation methods are based on climatological data which vary from empirical relationships to complex methods such as the Penman combination method Penman 1948, based on physical processes. These different methods of ET estimation can be grouped into two types based on the technique uses the first traditional methods based on GIS and the second is the remote sensing methods, the equations of the methods are given in Table 1.

The performance of different ET estimation methods varies with availability of data and climatic conditions, and the data requirements vary from method to method. Furthermore, ET estimations depend upon the quality of the data and meteorological data.
Therefore, it is very difficult for users to decide upon an appropriate ET estimation method among the different available methods for a particular station given the available data. Thus, there is a need to develop a tool not only for estimating the ET but also to decide on the best ET method for given data availability and climatic conditions.

This study attempts to develop a regional evapotranspiration model, which can be used as a decision support system to estimate daily ET for hydrological and agricultural planning aspect.

The main objective of this research was to develop, comparison and test a decision support system for estimating the regional daily ET under different data availability and climatic conditions. The performance of five Remote sensing ET estimation methods and six traditional methods based GIS against the Penman- Monteith method was also tested for three locations with different data availability and climatic conditions.

Table 1. Different ETo Estimation Methods, Governing Equations and Time Scale of Calculations

Grope	Approach	Method of ET estimation	Equations used	Reference
Remote Sensing (RS)	Remote Sensing (RS) (energy balance)	SEBAL	$\lambda ET_{ins} = Rn - G - H$ $\lambda E = R_n - (G_0 + H)$ $\Lambda = \frac{\lambda E}{\lambda E + H} = \frac{\lambda E}{R_n - G_0}$ $ET_{24} = \frac{86400 \times 10^3}{\lambda \rho_w} \Lambda R_{n24}$	(Basteaanssen et al ,1998)
RS	RS (energy balance)	SEBAL$_{-ID}$	$ET_{inst} = 3600 \frac{LE}{\lambda \rho_w}$ $ET_r F = \frac{ET_{inst}}{ET_r}$ $ET_{24} = C_{rad} (ET_r F)(ET_{r\_24})$	(Tasumi. Et al, 2000)
RS	RS (energy balance)	modified SEBAL (M-SEBAL)	$PET_{24} = \frac{Rn_{24}}{\lambda E * \rho_W}$ $EF = \lambda E / Rn - G$ $ET_{24} = EF(Rn - G)_{24}$	Almhab et al,2007a,b,c
RS	RS Vegetation index	Biophysical	$ETc = ETo[1-(VImax- VI)/(VImax - VImin)]^n$	Kustas and Norman (1996) Almhab and Busu ,2008 b
RS	RS Surface temperature	Simplified energy balance	$ET = A - B\ (dT)$	Jackson et al. (1977), and Almhab and Busu ,2008c,d
*Hydrology modeling (H) based GIS	Combination	FAO-56 Penman-Monteith FAO	$ETo = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{(T_{mean} + 273)} u_2 (e_a - e_d)}{\Delta + \gamma^*}$	FAO-56(Allen. Et al,1998)
*H-GIS	Combination	FAO-24 corrected Penman	$ETo = c\left[\frac{\Delta}{\Delta + \gamma}(R_n - G) + \frac{\gamma}{\Delta + \gamma} 2.7\, W_f (e_a - e_d)\right]$	FAO-24 Doorenbos and Pruitt (1977)
*H-GIS	Radiation	FAO-24 Radiation	$ETo = a + b\left[\frac{\Delta}{\Delta + \gamma} R_s\right]\frac{1}{\lambda}$	FAO-24 Doorenbos and Pruitt (1977)
*H-GIS	Radiation	Priestley-Taylor	$E_p = \alpha \frac{1}{\lambda} \frac{\Delta}{(\Delta + \gamma)}(R_n - G)$	Priestley and Taylor, 1972
*H-GIS	Temperature	Hargreaves	$ETo = 0.0023 R_A \sqrt{TD}(T_{mean} + 17.8)$	Hargreaves and Samani (1985)
H-GIS	Temperature	SCS Blaney-Criddle	$ETo = a + bf$	Doorenbos and Pruitt (1977)

Note: All symbols are explained in the Notation.

*This models have calculate reference ET (ETo) which was multiplied by crop coefficient (Kc) map of the study area in order to estimate the actual crop evapotranspiration. While the remote sensing methods estimate the actual direct evapotranspiration.

Despite numerical discrepancies, most of the available ET methods can effectively capture the time series structure, which can avail in the ET record, solely because, the inherent characteristics of most methods contain a radiation component in their model structure, which is noted to cause three-fourth of water loss through evaporation (Moges et al, 2002).

3. GIS and Spatial Decision Support Systems

A Geographic Information System (GIS) is a computer-based system that provides the following four set of capabilities to handle georeferenced data: input; data management (data storage and retrieval); manipulation and analysis; and output. The capability of manipulation and analysis of row data and conversion into more useful and easily readable information is probably the major strength of GIS.
GIS uses raster and vector structures to build digital geographic representations of the real world. Because the real world is very complex the representations are simplification and generalization of the real world referred as data model (de By, 2001; Bonham-Carter, 1994).

This support that GIS provides to the study of geographic phenomena by representing it digitally in a computer and allowing its visualization in various ways which has lead to the development of Spatial Decision Support Systems (SDSS). Malczewski (1999) defines a SDSS as computer-based systems that lie at the interaction of two major trends of spatial sciences: GISci (geographic information sciences) which have resulted in a significant body of knowledge about spatial and attribute data processing in a GIS environment, and the analysis which has generated a significant body of knowledge about modeling. The confluence of these two trends forms the two major resources with which the decision makers interact in the process of dealing with semi-structured spatial problems. He describes a SDSS in three major components (Figure 1): a database management system (DBMS) and geographic database, a model-based management system (MBMS) and model base; and a dialogue generation and management system (DGMS).

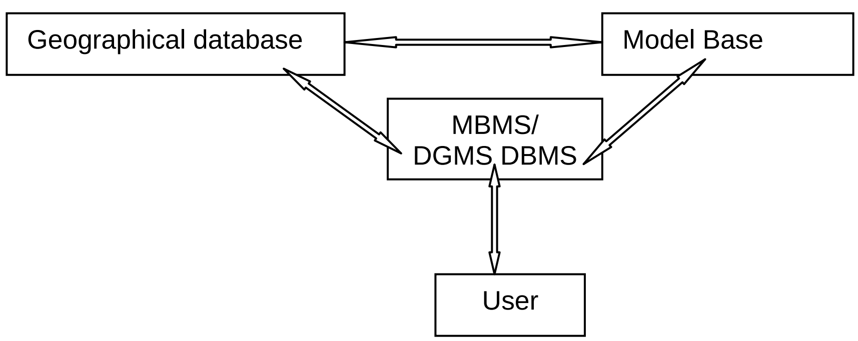

Figure 1 Components of SDSS (Malczewski, 1999)

A GIS was utilized to manage the satellite and ground-based data. Regional ET was estimated from the data layers in the GIS. In order to efficiently manage and manipulate the satellite images and ground data, the GIS was used to manage the large amount of satellite and ground data. The GIS was implemented by the ERDAS Imagine software package.

2. Sana'a Basin Yemen

The Sana'a Basin is located in the western highlands of Yemen opposite the Red Sea and the Gulf of Aden (figure 2). It is mostly an intermountain plain surrounded by highlands from the west, south and east. On a regional scale, the Basin extends across the central part of the Sana'a Governorate (figure 1) and covers about 24% (3250 km2) of its total area (13,550km2).
There is a significant variation in altitude both east-west and north-south. The highest point in the Basin is in the southwest end (Jabal An Nabi Shu'ayb) and has an elevation of almost 3700 m above see level (m.a.s.L) The lowest which is (about 1900 m.a.s.l.) is in the northern extremity where the Wadi Al Kharid exits the main basin. The predominant climate is arid although semi-arid conditions prevail in localized areas, particularly along the western highlands.

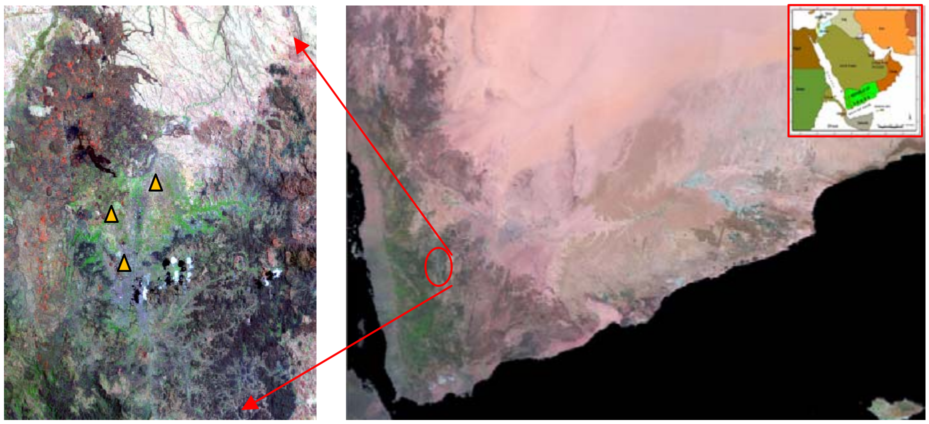

Fig. 2. The central Yemen mountains as seen on a True -color Landsat image acquired on june 1st (1998).
△ location of the climatic station in Sana'a basin.

3. DATASET

Satellite images LANDSAT5-TM , were evaluated for Land Surface Heat Fluxes distribution in Sana'a basin in central Yemen mountains. These overpass time of these images was 10.30of LANDSAT5-TM local time. Both images had favorable weather conditions with little clouds in the study area. Data from the field measurement area were available to assist the calculation of the Land Surface Heat Fluxes in the locations of the study area (Lat: 15.3 N, long: 43.15 E).

4. Description of Data

Three climatologically stations in Sana'a basin, namely, CAMA, NWRA, and Al-Irra Sana'a basin which are shown in figure 3, were selected for this study based on the location characteristics and data availability. The selected sites ranged in elevation from 1900 to 2500 m above mean sea level.

The latitude and the longitude of these stations were show also in table 2. All the stations are located in the arid region. Daily minimum and maximum temperatures, minimum and maximum relative humidity, solar radiation, and wind velocity were collected by the CAMA, NWRA and Al-IRRA in Yemen. The description of the different weather stations along with the data available and time scale is given in Table 2.

Table 2 Weather Station Description

	Region	Station name	Elevation m	Latitude N UTM(m)	Longitude E UTM(m	Time scale	Data available
1	Mountain Sana'a basin	CAMA	2216	1697.100	415.100	daily	Temp., RH, solar radiation, and wind velocity
2		Al-Iirra (AREA)	2200	1546.053	411.795	Daily	humid Temp., RH, wind velocity, sunshine hours,
3		NWRA	2275	1696.500	412.400	daily	humid Temp., RH, wind velocity, and sunshine hours

5. Comparison of Different Methods

For this research three climatic stations NWRA, CAMA and AREA, ET values were estimated by all applicable methods using the spreadsheet on Microsoft Excel, then connected with spatial geographic database . The FAO24-Penman method resulted in alfalfa reference evapotranspiration ETr which were adjusted to ETo by dividing the ETr values by 1.15. Then the reference ET (ETo) was multiplied by crop coefficient (Kc) map of the study area (the nearst field from the guage station and have good irrigation crop) to estimate the actual crop evapotranspiration. While the remote sensing methods estimate the actual evapotranspiration direct. The ET values obtained by different methods were compared with the FAO-56 Penman-Monteith ET estimate and SEE values were calculated as follows:

$$SEE = \left[\frac{\sum (Y_i - Y^{\cdot}{}_i)}{n-1} \right]^{0.5}$$

where SEE=standard error of the estimate; Y=ET estimated by the standard method Penman-Monteith method; $Y\hat{}$=corresponding ET estimated by the comparison method; and n=total number of observations. The SEE gives equal weight to the absolute differences between the standard method and the comparison method. It is a measure of the goodness of fit between the ET values estimated by the different methods and the standard method. The SEE has units of mm/day and n-1 degrees of freedom.
Linear regression analysis was carrid out between the ET estimates and comparison methods as follows:

$$ET_{Penman\text{-}Monteith} = b * ET_{method}$$

where b=regression coefficient. Regression through the origin was selected to evaluate the goodness of fit between the ET method estimates and the Penman-Monteith estimates because both values should theoretically approach the origin when the actual ET is zero.

6 Result and discusion

6.1 Regional DSS-ET maps for Sana'a basin, Yemen

The chosen stations CAMA,NWRA and Al-Irra, are sited in middle of the basin. This is located in an arid region, the DSS selected the M-SEBAL to give best result for estimating ET when the metrological data is mean daily as the case in CAMA and NWRA stations, then the $SEBAL_{-ID}$, SEBAL as the best method for estimating ET, when all the metrological data available, accuracy and instantaneous data as the case in AlIrra station. To verify the decisions of the DSS, the model was run using all available data except wind speed. In this case, the DSS gave the simplified method as the best ET estimation method because the data needed only the air temperature instantaneous, on Table 4 to 7. Values of ET estimated by different methods versus FAO Penman-Monteith for **CAMA station** Sana'a basin. Wind speed is required for applying any combination, SEBAL, $SEBA_{-ID}$, M-SEBAL and Biophysical method.

The hydrological models based GIS identified FAO Penman-Monteith as the best method for estimating ET. To verify the decisions of the DSS, the model was run using all available data except wind speed. Also the DSS gave the Hargreaves method as the best ET estimation method because it can accommodates all the available data, the DSS estimated net radiation from extraterrestrial radiation and sunshine hours, and selected the FAO Penman-Monteith method as the best method for CAMA. The model selected the FAO 24 radiation method as the best in the absence of wind speed data. However, the Hargreaves method was the best method when the maximum and minimum temperatures, maximum and minimum relative humidity, and wind speed were used as input to the model. This is because solar radiation or sunshine hours are essential for applying all combination and radiation methods as well as the SCS Blaney-Criddle method.
The model selected the FAO Penman-Monteith method for stations located in the regions and when monthly temperature, relative humidity, wind speed, and sunshine hours were used as input. The Hargreaves method was the best method when temperature, relative humidity, and wind speed or temperatures alone were used as input to the

model. Also, when the model was used with temperature, relative humidity, and solar radiation, it selected the FAO24 Radiation method as best. All these decisions made by the DSS coincide exactly with ASCE rankings (ASCE, 2002 and Jensen et al. 1990).

6.2 Comparison of Methods: Daily Estimates on CAMA station

The ET values estimated by all the eleven chosen methods were compared with the FAO Penman-Monteith estimates. Summary statistics of daily ET for the entire period is shown in Table 3. The SEBAL and Biophysical methods gave the maximum mean daily ET for the full period 5.8 and 5.6 mm/day respectively. Standard error estimates of the different methods ranged from 0.792 mm/day for the SEBAL to 1.46 mm/day for the SCS-BC method for the full time period. However, it varied from 0.79 mm/day for the Simplified method to 1.46 mm/day for FAO24 Penman for the peak month. The peak month SEE estimate was greater than that for all periods estimate for all methods except the Hargreaves and Priestley-Taylor.

Table 3. Statistical Summary of Daily ET Estimates for CAMA Stations

Statistical	ET method									
parameter	FAO56 PM	FAO24 P	FAO-R	PT	HG	SCS-BC	SEBAL	SEBA_ID	M-SEBAL	Bio	Simp
Mean ET mm/day	3.2	4.1	3.4	3.9	4.6	3.0	5.8		4.8	5.6	3.8
Weight Ranking	38	37	33	33	19	28	68	69	62	46	27
Normalized weight	2.53	2.467	2.2	2.2	1.267	1.857	4.533	4.9	4.1	3.06	1.80
Reciprocal weight	6.16	5.66	5.167	5.167	3.5	4.7	11	11.167	10.33	7.5	5.250
Weight $(n-rj+1)^p$, p=2	158	149	133	133.0	91	116	290	297	272	192	2.345
SEE mm/day	1.411	1.175	1.356	1.225	1.055	1.468	0.792		1.009	0.834	1.251
WSEE mm/day	1.044	0.870	1.004	0.907	0.781	1.086	0.586		0.747	0.617	0.925
b	1.00	1.281	1.063	1.219	1.438	0.938	1.813		1.500	1.750	1.188
%PM	100	128	106	122	144	94	181		150	175	119

Note: SEE standard The latter method predicted similar values of SEE for all periods and the peak error estimate; WSEE =weighted standard error estimates calculated as 0.74 SEE ; R^2 = coefficient of determination; *b*=regression coefficient; and % of PM percentage of FAO Penman-Monteith value.

All of the remote sensing method the SEBAL yielded very high values of the coefficient of determination when compared with the FAO Penman- Monteith estimates. The simplified methods over predicted daily ET for all periods. These two methods over predicted when the wind velocity was very high which ultimately affected the wind function component of these two ET estimation methods.

The two combination equations, the FAO-R and FAO-24 Penman yielded very good values of the coefficient of determination when compared with the FAO Penman- Monteith estimates. The SEBAL and Biophysical methods over predicted daily ET for all periods and the peak month. These two methods over predicted when the wind velocity was very high which ultimately affected the wind function component of these two ET estimation methods.

6.3 Comparison of Methods: Daily Estimates in NWRA station

Summary statistics of daily ET in NWRA station for the entire period was given in Table 4. the FAO56 PM and SCS-BC methods gave the maximum mean daily ET for the full period 5 and 4.9 mm/day respectively. Standard error estimates of the different methods ranged from 0.964 mm/day for the FAO56 PM to 1.303 HG method.

Table 4 Statistical Summary of ET Estimates for NWRA Station

Statistical	ET method										
parameter	FAO56 PM	FAO24 P	FAO-R	PT	HG	SCS-BC	SEBAL	$SEBA_{ID}$	M-SEBAL	Bio	Simp
Mean ET mm/day	5.0	4. 0	3.9	3.9	3.6	4.9	4.6		3.8	4.6	3.7
Weight Ranking	38.0	37	33	33	19	28	68	69	62	46	27.0
Normalized weight	2.533	2.467	2.2	2.2	1.267	1.857	4.533	4.9	4.1	3.06	1.8
SEE mm/day	0.964	1.200	1.225	1.225	1.303	0.986	1.055		1.251	1.055	1.276
WSEE mm/day	0.713	0.888	0.907	0.907	0.964	0.730	0.781		0.925	0.781	0.945
b	1	0.8	0.78	0.78	0.72	0.98	0.92		0.76	0.92	0.74
%PM	100	80	78	78	72	98	92		76	92	74

The M-SEBAL down predicted daily ET by 8, but gave the SEE 1.055 mm/day. The HG method lower estimated 72 and the other methods underestimated -18% Mean daily ET. Overall, the SCS-BC and SEBAL methods predicted the FAO Penman-Monteith ET the best. The SEBAL method has the lowest SEEs and ranked second, SEBAL-ID the first ranking, and other methods ranked in decreasing order are M-SEBAL, FAO-Penman Monteith, FAO Penman, FAO radiation, Priestley-Taylor, SCS- Blany Creadel, simplified, and Hargreaves.

As discussed earlier, the purpose of standardization of the methods is to have equivalent evaporation estimates from all methods when they are applied as a single evaporation estimating method. As FAO Penman-Monteith equation is universally established and accepted method for estimating evaporation, it was nominated as the basis of standardizing other methods. All stations which contain parameters for FAO Penman-Monteith method was selected and FAO Penman evaporation was estimated.

6.4 Comparison of Methods: Daily Estimates in Al-irra station

Table 5 shows the comparison of daily ET estimates for Al-Irra Station, between the FAO Penman-Monteith and all the combination, radiation, Temperature and Remote Sensing methods in A-Irra station Sana'a basin Yemen. The Hargreaves method yielded the minimum mean daily ETo of 3.2 mm/day, The SEE of different methods ranged from 0.92 mm/day for the SEBAL to 1.75 mm/day for the $SEBAL_{-ID}$ method Table 6.

The SEBAL over predicted mean monthly ET by 20, but gave the lowest SEE 0.68 mm/day. The simplified method lower estimated 15% and the other methods underestimated ±12.5% Mean monthly ET Table6, the FAO-24 radiation method overestimated ET especially during the first three months when satellite image captured. The Hargreaves method lower predicted ET by about 20%, and yielded the SEE 1.41. Because maximum and minimum temperature difference is very high in this station, these deviations are expected, because the Hargreaves method is the only method that requires measurement of only one daily parameter, air temperature. And $SEBA_{-ID}$ yielded the maximum SEE 1.75. Overall, the $SEBAL_{-ID}$ method predicted the FAO Penman-Monteith ET as best. The SEBAL method has the lowest SEEs and ranked second, $SEBAL_{-ID}$ the first ranking, and other methods ranked in decreasing order are M-SEBAL, FAO-Penman Monteith, FAO Penman, FAO radiation, SCS- Blany Creadel, Priestley-Taylor, simplified, and Hargreaves.

Table 5 Statistical Summary ET Estimates for Al-Irra Station

Statistical parameter	FAO56 PM	FAO24 P	FAO-R	PT	HG	SCS-BC	SEBAL	SEBA$_{ID}$	M-SEBAL	Bio	Simp
	ET method										
Mean ET mm/day	4.0	3.5	3.5	3.5	3.2	4.1	4.8	4.0	3.6	4.6	3.4
Weight Ranking	38.000	37	33	33	19	28	68	69	62	46	27.0
Normalized weight	2.533	2.467	2.2	2.2	1.267	1.857	4.533	4.9	4.1	3.06	1.8
SEE mm/day	1.079	1.329	1.329	1.329	1.411	1.175	0.920	1.751	1.303	1.055	1.356
WSEE mm/day	0.798	0.984	0.984	0.984	1.044	0.870	0.681	1.296	0.964	0.781	1.004
B	1	0.875	0.875	0.875	0.8	1.025	1.2	1	0.9	1.15	0.85
%PM	100	87.5	87.5	87.5	80	102.5	120	100	90	115	85

6.5 Comparison of Methods: monthly Estimates in Al-irra station

Summary statistics of monthly ET for the entire period **in Al-irra station** was given in Table 6. The simplified and biophysical methods gave the maximum mean monthly ET for the full period 5.8 and 5.6 mm/day. Standard error estimates of the different methods ranged from 0.792 mm/day for the simplified to 1.46 HG method.

The method was found to over predict during the period of satellite image available tables above, when the solar radiation values were high in comparison to other months. The SEE of this method was found to be higher than that of the FAO24R method for all periods and the peak month. The Hargreaves (HG) method under predicted ET for all periods 18% and gave a lower value of SEE for the peak month than for all periods. The SCS Blaney-Criddle method (SCS BC) gave a high coefficient of determination of 0.95 for all periods, but ET values were overestimated for both all periods 14%.

The PT method under predicted ET by 13% compared to the standard estimate. The regression coefficient was close to unity and the SEE was found to be 0.97 and 0.65 mm/day, respectively, for all periods and the peak month. This may be because the data from the Al-Irra site were used to derive the coefficients of the Hargreaves method. Based on the weighted average SEE, the different methods ranked in decreasing order are SEBAL$_{-ID}$, SEBAL, M-SEBAL, Biophysical , FAO Penman Monteith. FAO Penman, FAO-24 radiation, Priestley-Taylor, SCS Blaney-Criddle, Hargreaves, , and simplified method.

Table 6. Statistical Summary of monthly ET Estimates for Al-Irra Station

Statistical parameter	FAO56 PM	FAO24 P	FAO-R	PT	HG	SCS-BC	SEBAL	SEBA$_{ID}$	M-SEBAL	Bio	Simp
	ET method										
Mean ET mm/day	4.1	3.1	3.2	3.4	3.0	3.9	5.1	4.9	4.2	5.6	5.8
Weight Ranking	38.000	37	33	33	19	28	68	69	62	46	27.0
Normalized weight	2.533	2.467	2.2	2.2	1.267	1.857	4.53	4.9	4.1	3.06	1.800
SEE mm/day	1.175	1.439	1.411	1.356	1.468	1.225	0.942	0.986	1.151	0.834	0.792
WSEE mm/day	0.870	1.065	1.044	1.004	1.086	0.907	0.697	0.730	0.851	0.617	0.586
R^2	0.99	0.966	0.847	0.928	0.565	0.949	0.842	0.872	0.897	0.640	0.594
b	1	0.756	0.780	0.8	0.731	0.951	1.243	1.195	1.02	1.36	1.41
%PM	100	75.6	78.0	82.9	73.17	95.12	124.39	119.51	102.4	136.58	141.46

The regression coefficient used to adjust to Penman Monteith estimates, on average, is increased from 0.96 to 1.81 for all the stations. No apparent trend exists in other methods. Typical plots for Sana'a Basin, NWRA, CAMA and Al-Irra.

Regional ET in Sana'a basin, Yemen was calculated by using the all the combination, radiation, Temperature and Remote Sensing methods (SEBAL, $SEBAL_{ID}$, M-SEBAL, Biophesical and simlifield methods) some of the ET maps ploted in figure3 and 4 and the ET layers from the combination, radiation, and Temperature based in the GIS. ET contour map of interpolated ET show in figure 5. As shown in both Figures 3 to 5, the highest ET rate

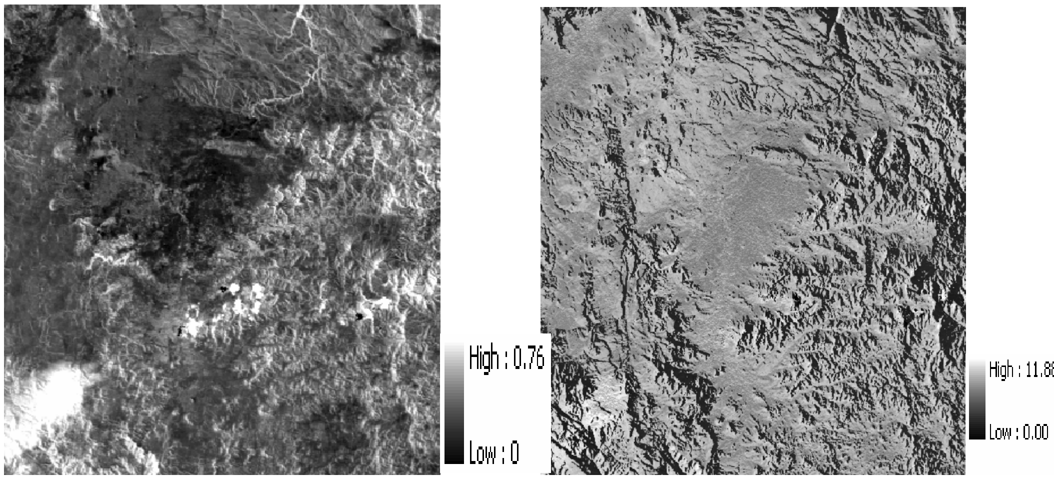

Figure 3 Instantaneous EF(at satellite image time) values(left) and 24-hour ET values(right) for the Sana'a basin, Yemen.

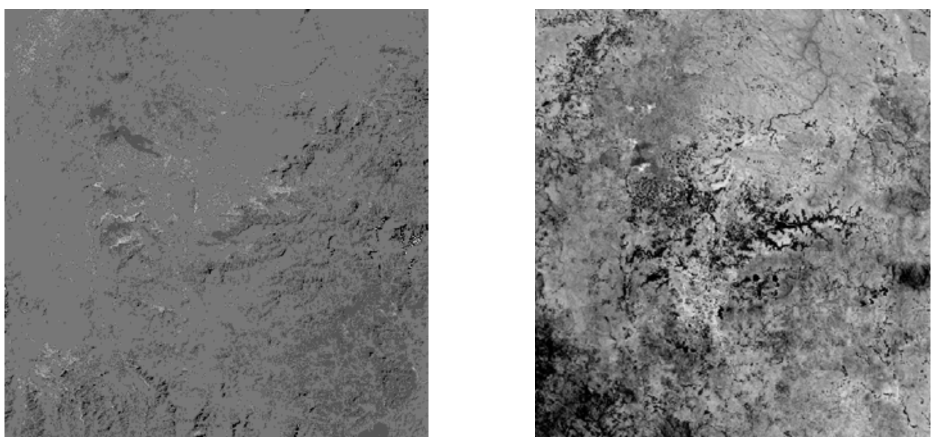

Figure 4 Compeering ET value for AREA station Sana'a **b**asin-Yemen

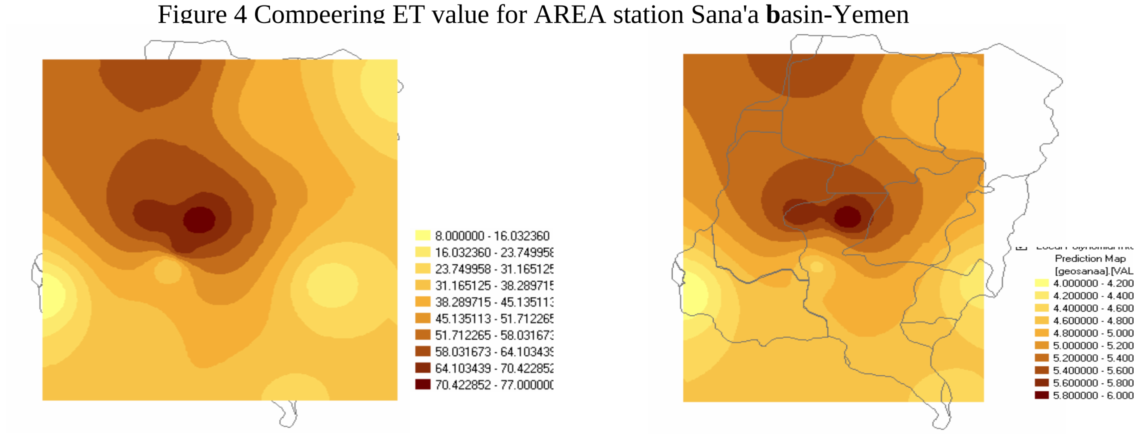

Figure 5 computing monthly(left) and daily (right) ET by DSS-ET for Sana'a basin, Republic of Yemen.

appears over the western watershed. However, the interpolated ET in traditional method displays a higher value along the zones boundary due to the extrapolation from further distance away. ET maps as remote sensing methods, on the other hand, displays a more evenly distributed and detailed contour due to the spatially distributed ET from remote sensing method. The pattern of excessive values along the extrapolating boundary is more noticeable if there are fewer weather stations in the region.

Using all the combination, radiation, and Temperature and Remote Sensing methods in the available Satellite image data and climate data for Sana'a basin. Figure 6 show the contrast between the daily ET value for Al-Irra (left) and CAMA (right) station Sana'a **b**asin-Yemen.

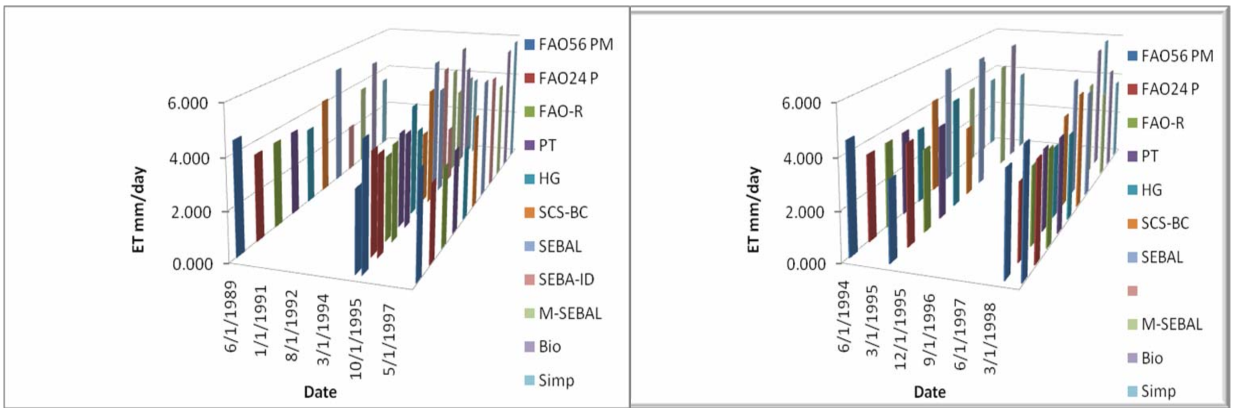

Figure 6 Compeering ET value for Al-Irra (left) and CAMA (right) station Sana'a **b**asin-Yemen

7. Comparison between DSS-ET with other works

Table 7 comparison between DSS-ET with other works

Parameter	**Biju A. et al 2002**	**EVAPDSS Moges,S.A,et al,2002**	**DSS-ET (this study)**
ET type focuses	Reference ET	Potential ET	Actual ET
Based on	User-defined option	– Arc View GIS	ERDAS& Arc GIS
Database	access	HEC-HMS	Geo-database
No. Models use	6	8	11
Method of sitting	ranking	Stochastic modeling	Rank weight MCDM-GIS
Layout preparation	Point ETr	Plot regional PET	Raster &image Regional ET
Type Models use	Traditional method	Traditional method and confer grid GIS	Remote sensing Method, Traditional method on GIS grid
Spatial functions supported	None	-	Buffer, reselect,
Result	Number point	Map grid	Map grid , raster, image
Running different scenarios with different criteria	no	no	yes

8. CONCLUSION

A Decision support system (DSS- ET) that can effectively use the state of the art technology of Remote sensing and GIS, combination of various spatial and hydrology modeling technique was developed to effectively use the available limited climatic data to estimate actual crop Evaporation.
For the three stations NWRA, CAMA, and Al-Irra, ETo values were estimated using all applicable methods. These values were compared with the FAO Penman-Monteith ET estimates, which were taken as standard. For the CAMA station, the performance of the SCS- Blaney-Criddle method was in close agreement with the FAO Penman-Monteith method. For , the FAO-24 radiation predicted the FAO Penman-Monteith ETo accurately.
For the NWRA station, the performance of the SCS- Blaney-Criddle method and SEBAL were in close agreement with the FAO Penman-Monteith method. For the Al-Iraa station, the $SEBAL_{ID}$ method predicted the FAO Penman-Monteith ET to be more closely for the entire period and the daily and monthly observations.

9.Notation:

The fallowing symbols are used in this paper

β	Bowen Ratio
C_p	Air specific heat at constant pressure
C_s	Soil surface air specific heat at constant pressure
d_s	Distance Sun-Earth
dT	Soil to atmosphere temperature difference
e_{sat}	Atmospheric saturated vapor pressure
e_{act}	Atmospheric actual vapor pressure
E	Evaporation
EF	Evaporation Fraction
ER	Evaporation Ratios
E-Pan	Pan Evaporation
ET	Evapotranspiration
ETa	Actual Evapotranspiration
ETas	Actual Evapotranspiration calculated by SWAP
ETo	Grass Reference Evapotranspiration
EToF	ETo fraction
ETr	Alfalfa reference evapotranspiration
ETrF	ETr fraction
ETs	Seasonal Evapotranspiration
ET_{pot}	Potential Evapotranspiration
FEC	Forced end of crop
g	Gravitational force
G_0	Soil Heat flux
H	Sensible Heat Flux
HG	Hargreaves
NWRA	National Water Resources Authority
PM	Penman-Monteith
r_{aH}	aerodynamic resistance for Heat Transport
Rn	Net Radiation
r_v	Aerodynamic surface resistance to vapor transport
r_s	Bulk surface resistance to evapotranspiration
RS	Remote sensing
SEBAL	Surface Energy Balance Algorithm for Land
$SEBAL_{ID}$	SEBAL IDAH UNIVERSITY
M-SEBAL	Modified SEBAL -UTM
T_0	Land surface temperature
T_a	Air temperature
T_{aero}	Aerodynamic surface temperature
T_{rad}	Radiation surface temperature
T_s	Soil skin Temperature
TM	Thematic Mapper
U^*_{eff}	The effective fraction velocity
u_z	The wind speed measured at height z
VI	Vegetation index
C_{rad}	Correction factor for solar radiation
YEMN	Republic of Yemen
Υ	Psychrometric constant
z	The height
z_{oh}	Roughness length for heat
z_{om}	Roughness length for momentum
б	Stephan Boltzmann constant
Td	Soil surface air specific heat at constant pressure
λ	Latent heat of vaporization
λE	Latent heat flux
λE_{day}	Daily Latent heat flux
ε_o	Surface thermal emissivity
ρ_o	The surface btoadband albedo
ω_s	Solar angle hour
ϕ_{sun}	Zenith angle of the sun
β	Bowen Ratio
λ	Latent heat of vaporization
λE	Latent Heat Flux
ρ_{air}	Moist air density
ρ_{va}	Atmospheric vapor density
ρ_s	Soil surface air density

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