DETERMINATION OF DAILY REGIONAL SCALE ACTUAL EVAPOTRANSPIRATION FOR INDUS SUB-BASIN USING LANDSAT ETM +

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Abstract:

Information on evaporation and transpiration from the agricultural field is an important requirement to manage water resources efficiently. The estimation of evapotranspiration through field observation is a laborious and time taking exercise. Current study gives estimation of regional scale evapotranspiration using remotely sensed data and ground based data for central Punjab in Pakistan. Surface Energy Balance Algorithm for Land (SEBAL) has been used to estimate actual evapotranspiration (ETa). SEBAL uses only seven bands (visible, near infrared and thermal infrared) of the Landsat7-ETM+ satellite sensor to estimate per pixel value of actual ETa .Ground based data is also synergized with the satellite data to enhance the validity of the results. The results reveal that using SEBAL model to estimate ETa is an appropriate method in Faisalabad & surroundings.

Key Words: *Actual Evapotranspiration, SEBAL, Remote Sensing, Landsat ETM+*

Introduction:

Agriculture is the major component of Pakistan's economy. It directly contributes 25 percent to Gross Domestic Product (GDP) and provides employment to 44 percent of the total labour force of the country. (Pakistan 2000 Agricultural Census, 2000) In study area, both irrigated and rainfed agriculture are practised, however, rainfed share is about 13% (Agriculture statistics of Pakistan, 2005-2006). Water resource is the most prominent limiting factor in obtaining optimum yield. In addition to scarcity of water, the conventional impropriate flood irrigation results into great losses to soil and water resources. Excessive amount of water, on one hand, leaches the soil nutrients to deeper layers of soil beyond the reach of the plants, leaving rooting depth soil with less fertility, on the other, it causes water logging, which give rise to salinity as well. Therefore, application of optimum amount of water at proper interval as per crops' demand is utmost important.

Actual Evapotranspiration is one of the most useful indicators to describe whether the water is used efficiently or not. Variations in ETa, both in space and time are considered to be highly indicative for the adequacy, reliability and equity in water used (Doorenbos and Pruitt, 1977; Allen et al. 1998).

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Since 70% (90% in arid region) of total annual precipitation is lost in the form of ET (Duffie, J.A. and W.A. Beckman, 1980). Thus it is an important part of hydrological cycle and also a main part of energy balance, because when liquid water transfers to vapour it absorbs larger amount of heat energy. Therefore, to estimate the ET accurately is very substantial for understanding the larger-scale energy and water balance.

As it is evident that actual ET estimation using SEBAL, lysimeter and ET predicted using traditional methods suggested that SEBAL or similar methods hold considerable promise as efficient, accurate, and economical procedures to estimate and predict the actual evaporation values from irrigated lands throughout a growing season. (Dr. R.G Allen, et al., 2005) Surface Energy Balance Algorithm for Land (SEBAL) is one of the residual methods of energy budget to find actual ET, developed by Bastiaanssen, et al., (1998). It combines empirical and physical parameterization. The inputs is consists of satellite data as well as it includes local weather data (wind speed and temperature). By using the input data net solar radiation, albedo, NDVI, roughness length, and G (soil heat flux) are calculated. The sensible heat flux H is estimated by contrasting two points (i.e. wet and dry ground pixels). Then, the actual evapotranspiration is calculated as the residual of the energy budget (Bastiaanssen, et al., 1998), using ; $\lambda ET = R_n - G - H$ where Rn is net radiation, G is soil heat flux and H is sensible hear flux.

The subject could have been addressed judiciously if lysimeter and dense meteorological data of the region were available. However, the study is an effort to estimate the crop water demand with ground available resources and air born remote sensing as well. It would serve as the guiding material for the forming community to irrigate their crops as per their requirement. The saved water will help them to bring more area under crop in this densely populated region of Pakistan.

Study Area:

Study area consists of arid, semi-arid, irrigated and deserted regions which cover about 192347 square kilometer (475,300,49 Acres). The main target of this study is the area which is being irrigated by River Chenab. Its geographic location is 71.5o to 73.4o East, latitude 31.3o to 32.5o North Latitude, at an average elevation of about 200m above sea level as shown in fig 1. River Chenab and River Jhelum flows about 30 km and 100 km respectively in the North West of Faisalabad city while river Ravi meanders about 40 km off the city in the South East. Chenab canal is the main source of irrigation water. On average, the targeted area receives an annual precipitation of 450mm (Climatic Normals Pakistan; 1971-2000), which varies spatially and this amount of rainfall is either insufficient or having unreliable frequency. The climate of the study area is very hot in summer and moderate in winter. The average maximum and minimum temperature in summer are 39°C and 27°C respectively. While winter averages of maximum and minimum ranging between 22°C and 6°C respectively (Climatic Normals Pakistan; 1971-2000).

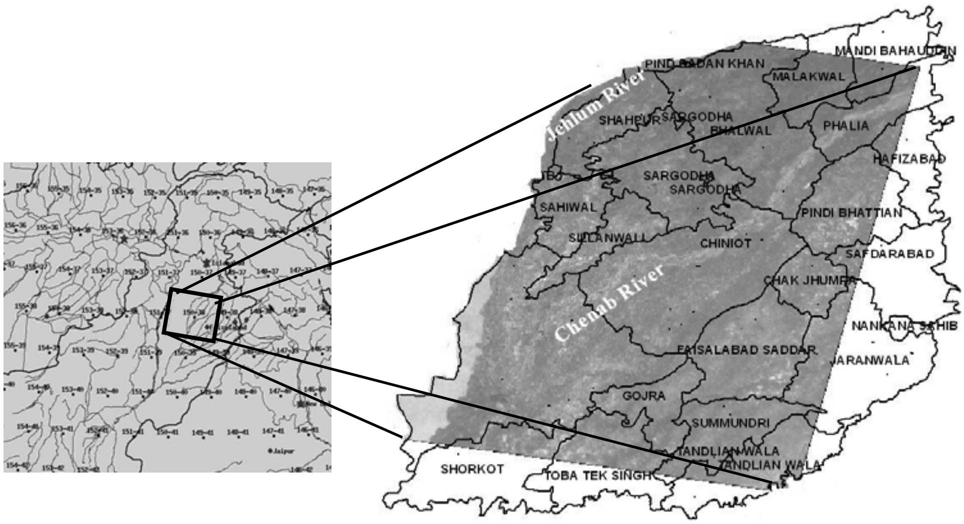

Figure 1: **Study Area**

Data and Methodology:

Material mainly includes satellite data but ground observed data is also included to increase accuracy. A Landsat ETM+ image (Path 150 Row 38), covering Faisalabad, Sargodha, Mianwali, Mandi Baha-ud-din, Hafizabad, Khushab and Bhakhar regions, was acquired on 20th October 2000 and downloaded from Global Land Cover Facility of the University of Maryland website.

Reference ET value is calculated using reference ET calculator developed by Dr. R.G. Allen using weather data. The reference evapotranspiration (ETr) is the ET rate expected from a well-defined surface of full-cover alfalfa. ETr is used in SEBAL to estimate the ET at the “cold” pixel and to calculate the reference ET fraction (ETrF). The value for reference ET is about 4.0 mm/day (calculated by using ET calculator). Reference ET is also obtained from Agromet Bulletin, October 2000, which is about 3.7 mm/day (Blaney - Criddle method) for Faisalabad. Here the mean value 3.85 mm/day is being used as input in SEBAL.

SEBAL algorithms, loaded and run by ERDAS “Modeler” tool, based on some empirical and non-empirical formulae for calculation of different parameters. The area is subdivided into two regions the one in the East of Chenab River and the other in the West of Chenab River. Algorithm is being applied separately on both regions to have more accuracy.

Net Radiation:

The first step in the SEBAL procedure is to compute the net surface radiation flux (Rn) using the surface radiation balance equation:

$$R_n = (1-\alpha)R_{S\downarrow} + R_L \downarrow - R_L \uparrow - (1-\varepsilon_O)R_L \downarrow \quad (1)$$

This is accomplished in a series of steps using the ERDAS Modeler tool to compute the terms in the equation 1. A flow chart and Model of the process is shown in Figure 2.

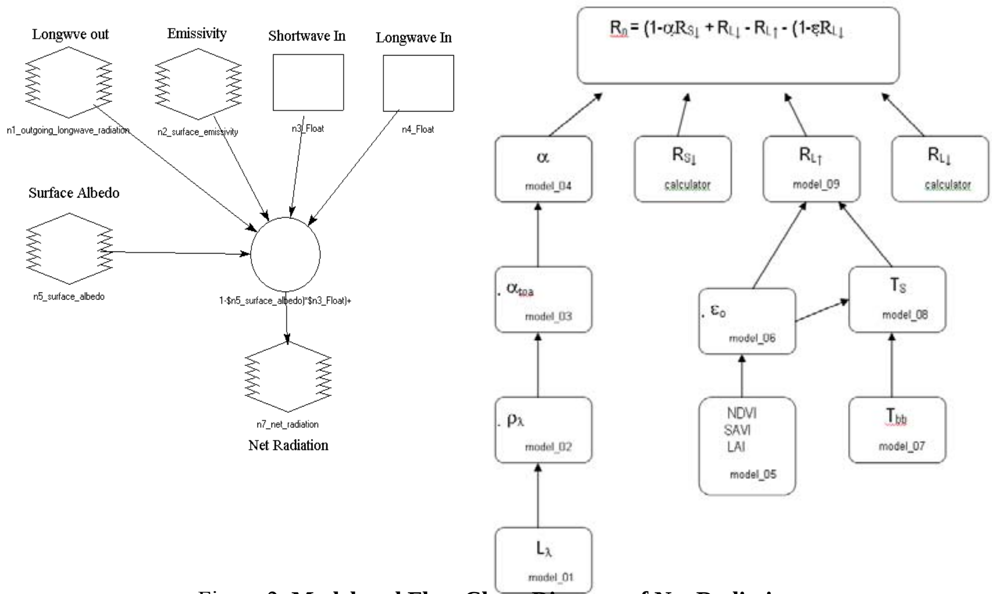

Figure 2: **Model and Flow Chart Diagram of Net Radiation.**

The reflectivity for each band is being calculated by using header file information, included in the image. Surface Albedo is derived by using

$$\alpha = \frac{\alpha_{toa} - \alpha_{path\_radiance}}{\tau_{SW}} \quad (2)$$

where; α_{toa} is surface albedo at the top of the atmosphere, values for αpath_radiance range between 0.025 and 0.04 and here 0.03 has been selected (Bastiaanssen, 2000), τ_{SW} is atmospheric transmissivity.

Incoming shortwave radiation value is estimated using

$$Rs_{\downarrow} = G_{sc} \times \cos\theta \times dr \times \tau_{SW} \quad (3)$$

where; Gsc is the solar constant (1367 W/m2), cos θ is the cosine of the solar incidence angle; taken from the header file and dr is the inverse squared relative earth-sun distance.

Outgoing longwave radiations are derived using the Stefan-Boltzmann equation

$$R_L \uparrow = \varepsilon_o \sigma T^4 \qquad (4)$$

for which NDVI, SAVI, LAI, surface emissivity and surface temperature model are being run in ERDAS Modeler tool.

Incoming Longwave radiations are calculated with the help of following equation

$$R_L \downarrow \; = \; \varepsilon_a \times \sigma \times Ta^4 \qquad (5)$$

Where; Ta ≅ Tcold at the "cold" pixel, σ is the Stefan-Boltzmann constant (5.67 × 10-8 W/m2/K4) and ε_a is atmospheric emissivity.

Soil Heat Flux:

To calculate soil heat flux, the empirical equation 6 is used (Bastiaanssen 2000), representing values near mid-day.

$$G / R_n = \frac{T_s}{\alpha(0.0038\alpha + 0.0074\alpha^2)(1 - 0.98 NDVI^4)} \qquad (6)$$

where; Ts is the surface temperature (oC), α is the surface albedo, NDVI is the Normalized Difference Vegetation Index, G is soil heat flux and Rn is the net radiation.

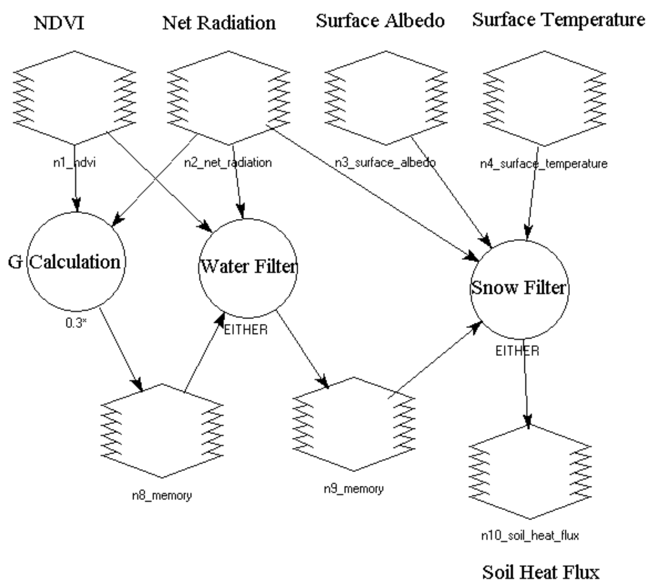

Figure 3: **Model for Soil Heat Flux**

Sensible Heat Flux (H):

Sensible heat flux is the rate of heat loss to the air by convection and conduction, due to a temperature difference. It is computed using the equation 7 for heat transport:

$$H = (\rho \times c_p \times dT) / r_{ah} \quad (7)$$

where; ρ is air density (kg/m3), cp is air specific heat at constant pressure (1004 J/kg/K), dT (K) is the temperature difference (T1 – T2) between two heights (z1 and z2) and rah is the aerodynamic resistance to heat transport (sm^{-1}).

Aerodynamic Resistance is the component of force exerted by the air on a liquid or solid object (such as a raindrop or airplane) that is parallel and opposite to the direction of flow relative to the object. This component of equation is derived by the following equation (Monteith, 1965)

$$r_{ah} = \frac{\ln\left(\frac{z_2}{z_1}\right)}{u_* \times k} \quad (8)$$

where; z1 and z2 are heights in meters above the zero plane displacement (d) of the vegetation, u* is the friction velocity (m/s) which quantifies the turbulent velocity fluctuations in the air, k is von Karman's constant (0.41)

Friction velocity is derived, using the following equation

$$u* = \frac{ku_x}{\ln\left(\frac{z_x}{z_{om}}\right)} \quad (9)$$

where; k is von Karman's constant, ux is the wind speed (m/s) at height zx, zom is the momentum roughness length (m), zom is a measure of the form drag and skin friction for the layer of air that interacts with the surface.

Surface Energy Budget Equation:

The net radiation flux (Rn) is the total amount of radiant energy that is available at the surface for warming the soil, warming the air, or evaporating soil moisture. This is written as the surface energy budget equation:

$$R_n = G + H + \lambda ET \quad (10)$$

where; Rn is the net radiation at the surface (W/m2), G is the soil heat flux (W/m2), H is the sensible heat flux to the air (W/m2), and λET is the latent heat flux (W/m2) for the time, when image was being scanned by the satellite. As Latent heat flux is the rate of latent heat loss from the surface due to evapotranspiration. It can be calculated using the following equation.

$$\lambda ET = R_n - G - H \qquad (11)$$

Reference ET Fraction (ETrF):

ETrF is similar to the well-known crop coefficient (Kc). ETrF is used to extrapolate ET from the image time to 24-hour period. This is computed using equation 12 with ERDAS Modeler Tool.

$$ETrF = \frac{ET_{inst}}{ET_r} \qquad (12)$$

where; ETinst is computed from Equation 11 (mm/hr) and ETr is the reference ET (mm/hr).

24-Hour Evapotranspiration (ET_24):

Daily evapotranspiration can be computed using the following equation.

$$ET_{24} = ETrF \times ET_{r\,(24\text{-hours})} \qquad (13)$$

Where; $ET_{r\ (24\text{-hours})}$ is the reference ET for 24 hours

Results & Conclusions:

Spatial distribution of surface temperature shows that the maximum temperature lies in lower & western part of Jhang, while the minimum in Mandi Bah-au-din. Similarly NDVI results are also evident that maximum NDVI value (0.86) is in Mandi Bah-au-din and minimum in lower & Western Jhang.

Actual ET results are being verified with the help of Reference ET and average Crop coefficient (Kc) data.

Table 1: **Spatial Distribution of Actual ET on 20 October, 2000**

Area	Average Crops Coefficient (K_c)	Reference ET (ET_r) mm/day	Actual ET ($K_c \times ET_r$) mm/day	Mean Actual ET (SEBAL) mm/day	Differenc e mm	% age Accuracy
Faisalabad	0.51	5.65	2.88	2.75	0.13	95.5
Jhang	0.50	4.63	2.32	2.58	- 0.26	90
Mandi Bahauddin	0.58	5.9	3.4	2.85	0.55	84
Sargodha	0.55	5.8	3.20	2.65	0.55	83

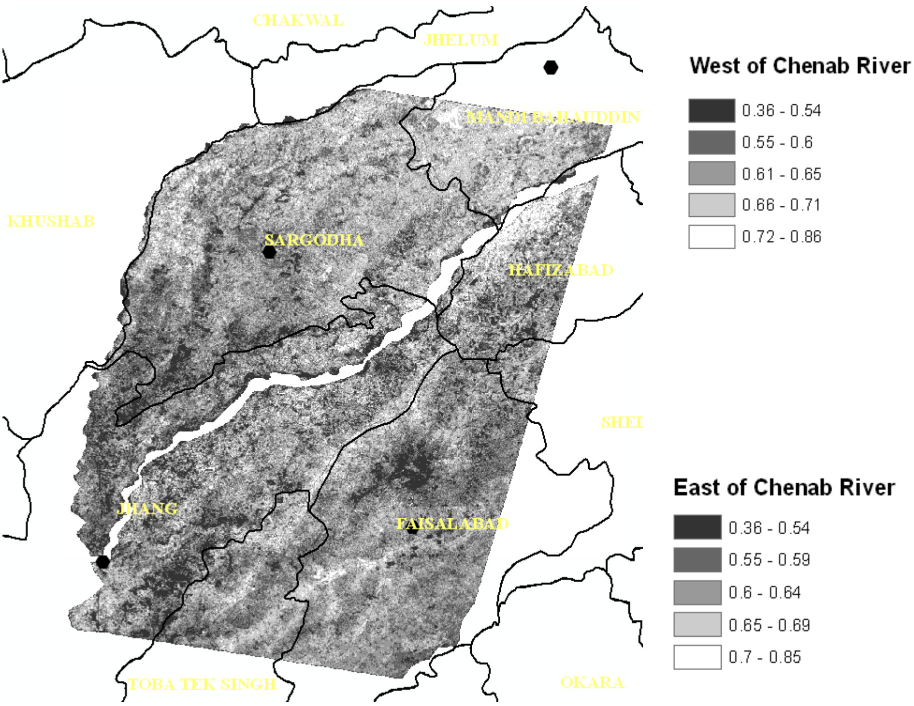

Figure 1: **NDVI Variations**

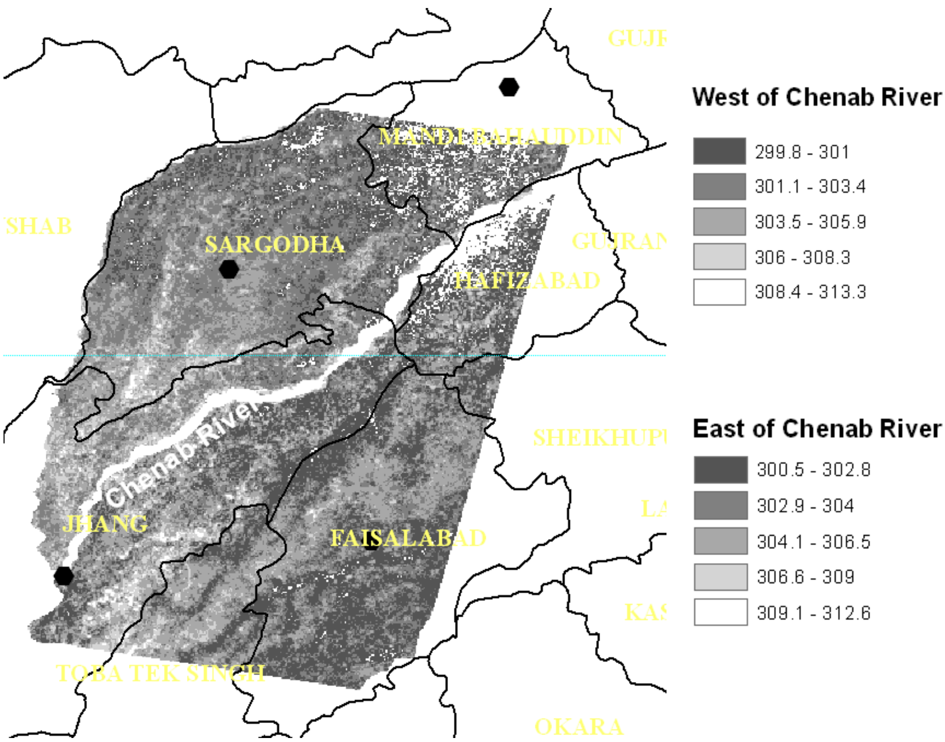

Figure 4: Temperature Variations (K)

The spatial distribution of actual ET on 20th October, 2000 is shown in table 01. Which demonstrates that maximum value of ET is in upper parts of the study areas like in Mandi Baha-ud-din and upper Sargodha, moderate values are in Faisalabad and upper Jhang, while minimum values lies in lower & western Jhang.

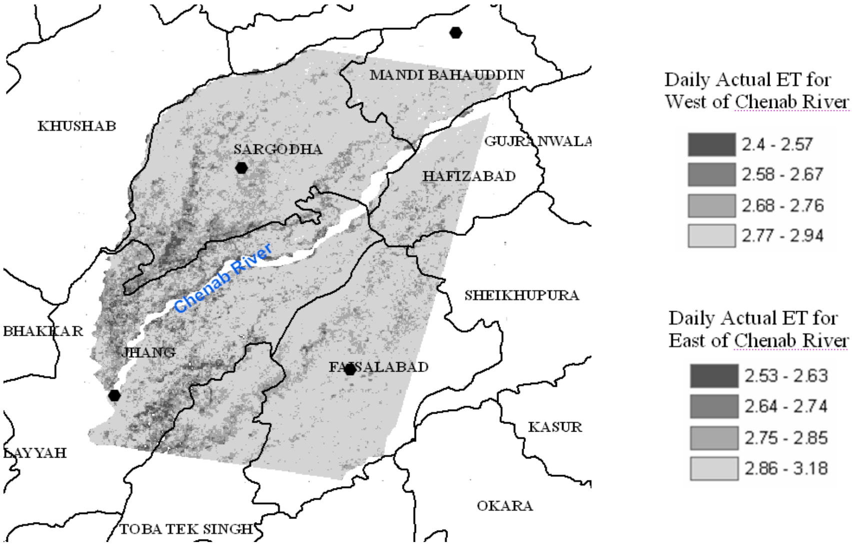

Figure 5: **Daily Actual evapotranspiration (mm/day)**

Actual ET varies about from 2 mm/day to 3 mm/day, regarding the area. The average of entire area is about 2.65 mm/day. The accuracy in Faisalabad & surrounding is about 95%, while it is 90% in Jhang area and was found about 83% in Sargodha region. It shows that SEBAL is appropriate method to calculate actual ET in this region.

Acknowledgement:

Special thanks to Dr. Qamar-uz-Zaman Chaudhry (Director General, Pakistan Meteorological Department, Islamabad). The cooperation of Dr. Ghulam Rasul (Director R&D, Pakistan Meteorological Department) has been essential and gratefully acknowledged. Authors are also thankful to Mr. Furrukh Bashir and Mr. Waqas Ahmad for their unbound help & support.

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