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State of art - geospatial energy balance models in estimation of evapotranspiration for sustainable agricultural water management at regional scale

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Abstract
The inextricable linkages between water, energy and food domains need an integrated strategy in ensuring food and water security and making agriculture and energy production in a sustainable manner worldwide. Agriculture is remained the biggest user of water of this century. The water usage in irrigation command can be reduced by applying precise quantities of water to crop by reducing evapotranspiration, percolation, leaching etc. Day by day, as freshwater turns into an inexorably rare asset, all chances for better management of water uses, in particular in irrigated agriculture, ought to be taken. Whatever may be the irrigation management strategy, crop water requirement calculation based on evapotranspiration and crop coefficient is a most prominent and successful technology. Because of the very high distribution of land vegetation, remote sensing could be perfect and ideal technique of Evapotranspiration (ET)estimation for these kinds of landscapes than the measurement at single weather station. But in most of the research the extrapolation from one weather to a large area is usual practice leads to over estimation of water requirement. In this paper tried to identify the gap among scientists and professionals, by outlining remote sensing techniques in estimation of evapotranspiration (ET). Some of the well-known methods of estimating ET using remote sensing energy balance models are SEBI, S-SEBI, SEBS, SEBAL, METRIC etc. Each method has its own advantages and disadvantages. An attempt is made in this paper to study the state of art of traditional and remote sensing technologies to estimate crop evapotranspiration. The fundamental theories, methods and different surface energy balance algorithms in estimation of ET with remotely sensed surface temperatures has been thoroughly discussed. This review would hopefully lead to more operational use of this information in management of water and energy at large scale.

Keywords: Evapotranspiration, Energy balance, Water management, Irrigation, GIS, Remote sensing models.

1. Introduction

Inter connections between water-food-energy is the heart of sustainable, economic and environmental development and protection. The demand for all three resources continues to grow for growing population, urbanization, needs and incomes, energy and water intensive goods, international trade, and climate change [1]. The Asian Development Bank (ADB) states that the global debate is not about water security or water scarcity in isolation. Instead, it is about the water-food-energy nexus. It is the growing demand for food, with its high-water requirement, superimposed on population growth, which crucially turns an abstract crisis into a critical and immediate one (Figure 1). Agriculture, the largest user of water accounts for 70 percent of total global freshwater withdrawals, the food production and supply chain consume about 30 percent of total energy consumed globally [2].

Energy is required in agriculture to produce, food delivery, transport to lift, treat, collect, pump, transport water. This situation is expected to be exacerbated in the near future as 60 percent more food will need to be produced in order to feed the world population in 2050 [2]. Total global water withdrawals for irrigation are projected to increase by 10 percent by 2050 [2]. Global energy consumption is projected to grow by up to 50 percent by 2035 [3]. In practical terms, it indicates a concept of systematic analysis of the interactions between the natural resources across sectors. For the water resource manager, in order to achieve a sustainable development an understanding of the physical laws and the natural systems that govern evaporation processes from the various surfaces of the earth need to be understood. ET stands a standout amongst the most difficult component to estimate as it relies upon different climatological parameters, for example, temperature, solar radiation, wind speed, and vapor pressure and furthermore physical soil properties, land cover changes.

The irrigated area occupies worldwide about 16% of the total agricultural area, but the crop yield is roughly 40% of the total yield. Hence, the productivity of irrigated land is 3.6 times that of unirrigated land. The monetary value of the yield of irrigated crops is some 6.6 times that of unirrigated crops. In irrigated land one grows crops with higher market values [4]. As per Irrigation statistics, 2017, the water used for irrigation is roughly 25% of the annually available water resources (14000 km^3) and 9% of all annual river discharges in the hydrological cycle. Hence, irrigation schemes in the world use about 3,500 km^3 water per year, of which 74% is evaporated by the crops. Hence, in the present review, an attempt is made to study the state of art of traditional and remote sensing technologies to estimate crop evapotranspiration. Which is a key factor for water and energy management and food production.

2. Role of Geospatial Technologies in estimation of crop evapotranspiration:

Evapotranspiration (ET) is the A physical processes whereby liquid water is vaporized and transferred from evaporating surfaces on the earth into the atmosphere. Water is lost by evaporation from soil, vegetation surface or atmosphere. vegetation, species, microclimate. Atmosphere evaporation might happen from irrigation, evaporation from soil is influenced by soil moisture, soil tilth, physical and chemical conditions of soil. Transpiration is evaporation from plant tissues. Evaporation and transpiration is together being named as evapotranspiration (ET) which is the guideline for irrigation water application [5]. Distinctive strategies/methods have been proposed ranges from straightforward experimental ways to complex and data consuming ones [6]. For decades, weather-based methods, soil moisture measurements, and surface energy balance approaches are being used majorly in estimation of land surface ET. Wide number of numerical models were presented for field to basin level ET estimations requires itemized and detailed information of soil, vegetation and atmosphere. It confines their application to the specific to long term input data. But Remote sensing-based energy balance models compute instantaneous ET as the residual term of energy budget at the satellite overpass, once net radiation, soil heat flux and sensible heat flux are derived [7, 11].

The operation of the earth system is close to an energy balance, it means an equal amount of energy enters into and emerges out of it. Consequently, the temperature conditions of the whole system unchanged relatively over a long period of time. However, variations over time and space persist within the earth system results from the changes in surface conditions, such as whether the surface is land, water or snow *etc*. Which leads to changes in the surface energy balance and also affects the amount of energy retained and distributed within the Earth system.

The global energy balance considers the energy flows within the climate system and their exchanges with outer space [12]. To plan irrigation and other hydrological approaches, among the different energy fluxes in the environment and Earth's surface, the information of sensible (H) and latent (LE) heat fluxes, as well as of soil moisture content must be considered (Figure 1).

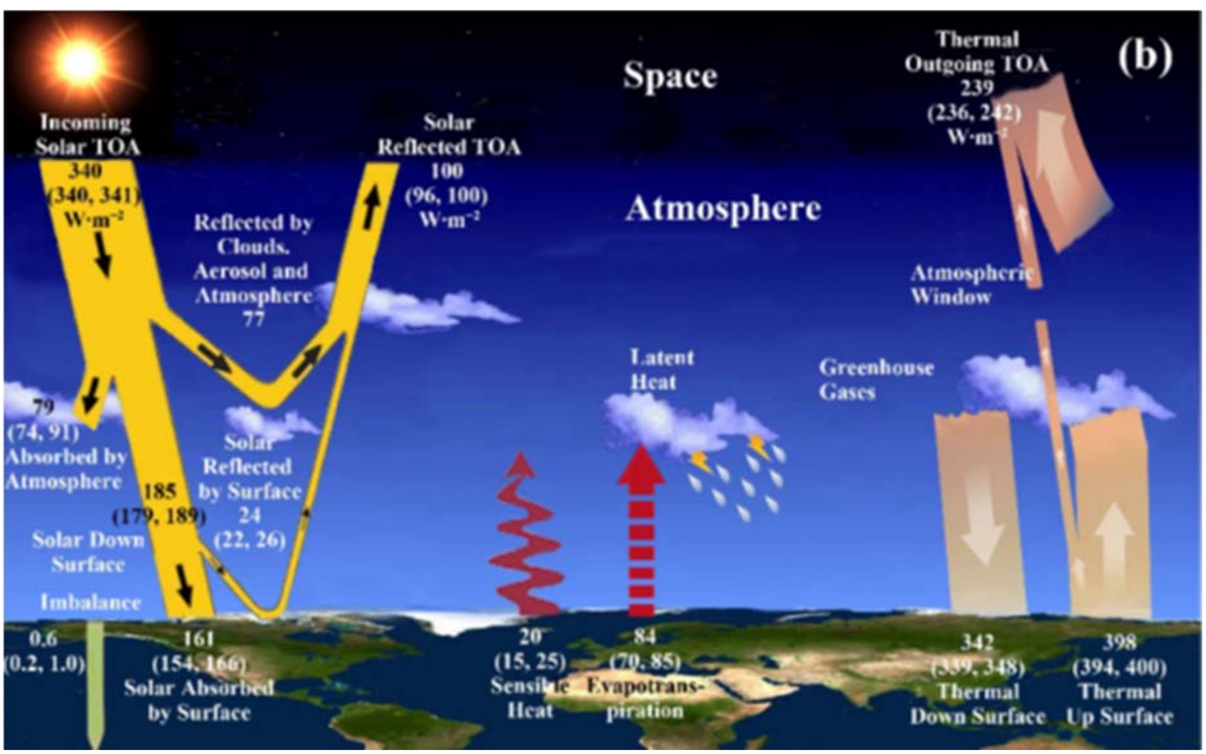

Fig 1: Schematic diagram of the global mean annual energy balance (Wm^{-2}) of the Earth. (Numerical values are taken from [11].

The typical drawback with conventional systems of ET estimation is that they exclusively give right evapotranspiration estimations for a homogeneous region around a meteorological station and that can't be extrapolated to other sites of non-homogeneous. However, remote sensing technology made it possible from a technical and economical purpose. Most of the research related to water application focused on quantifying potential evapotranspiration (ET) which is crop water use under non-stressed conditions, which not considers stress levels during different growth stages. The crop water use in consideration to stress is referred as the actual crop ET (ET_a). The lack of much research is because of the complexity of the interactions with other factors that also affect Et_a time consuming and expensive. Due to this, critical information on actual ET_a is missing. Such information would be critical to future determinations of both agricultural and urban water planning, irrigation systems used for environmental modification, food production, energy production and saving etc [13]. For this reason, regional scale estimation of crop actual evapotranspiration, crop coefficients (Kc) has been wide concentrated recently by joining standard meteorologic ground estimations with remotely sensing information. Remote Sensing integrated with Geographical Information System has been efficiently used in water resources management applications.

Precise estimation of ET in water resources management and development is necessary for long planning and implementing the schemes on ground. The use of remote sensing and geospatial techniques in water management took a new turn as these techniques were utilized in new approaches of assessment [14] Satellite images provide vital information on the understanding of water use and vegetation status. The most important development in the field of RS hydrology is the determination of distributed aerial actual ET from spectral satellite data, based on the surface energy balance approach. If this approach is validated by well-defined methods (e.g. ET by Lysimetric data sets) based on ground-observed data sets, then we can derive daily ET from RS data sets at regional scale [15].

FAO 2014, clearly stated that the satellite observations, combined with in-situ data, provide a unique source of consistent information about the natural environment, on which we rely to produce water, energy and food. Such findings are important to understand the intricate processes in natural environment and related human activities. Also provide information to multiple stakeholders and to manage the natural resources and ecosystems in a sustainable manner.

Diverse techniques have been developed to utilize satellite remote sensing information in surface flux estimation models. But, most existing schemes for ET estimation need ground observations that will be troublesome to get at large scales. Variety of sophisticated RS-based models and algorithms has been presented and for various vegetation classes in various scales. They are generally comparable within the pixel scale homogeneous spectral assumption. There remain open queries on the power of satellite remote sensing to give ET estimates free of ground observations in large areas.

3. State of art technologies for measurement of ET

The existing traditional techniques for estimation of ET includes evaporation from a water surface, use of climatological data, Lysimeters etc. Open pan-measurement technique proved its practical value and has been used successfully to estimate ET by observing the evaporation loss from a water, which gives effect of radiation, air temperature, air dampness and wind on ET.

Lysimeters provide a direct measure of the crop evapotranspiration (ETc). These are tanks filled with soil media, in which crops are grown under natural conditions. This method is frequently used to study to evaluate other ET estimation procedures. Lysimeters are weighing type or non-weighing type [16]. Lysimeters largely avoid errors made by traditional measurement systems, such as the class-A pans, or errors from soil-water measurements that are subject to subsurface heterogeneity [17]. The Bowen ratio (BR) is ratio of the sensible to latent heat fluxes [18]. BR is estimated on the temperature and humidity gradients across two fixed known heights above the surface. Bowen ratio flux towers are regarded as the most accurate methods of estimating ET at scales of 0.1 to 1 km [19]. But there are studies reported the BREnergy balance method failed to provide reliable estimation of evaporation. The criteria that have been found depend on the physical inconsistency of the data and on the resolution limits of the sensors [20, 21].

The eddy correlation (EC) is another widely applied method for the determination and monitoring of in situ energy elements and Co_2 and water vapour fluxes at a half-hour time scale [22, 23]. It was first developed in the 1950s by scientists from CSIRO in Australia. Presently it is stated as good method to directly estimate sensible and latent heats and it is widely accepted in many experiments. This method is generally used at the places where other methods for surface flux measurements, such as BR systems are difficult to use. The typical error of λE is about 5-20% or 20-50 Wm^{-2} [24, 25].

Water balance method used for basin scale used to estimate ET rates by comparing precipitation and runoff data. The water balance approach equation is

$$ET = P - O - \Delta S \qquad (1)$$

Where ET = Evapotranspiration; P = precipitation, O= outflow ΔS = change in water storage (lakes, reservoirs, groundwater). The water balance technique is an effective way to estimate the ET provided long term data on rainfall and stream flow are available for a given watershed (Ward & Trimble, 2004). Through the concept of water balance equation is simple for proper adoption, understanding of numerous hydrologic processes are required. Otherwise it causes huge errors in study processes [56].

Commonly employed ET mathematical estimation techniques are either empirical methods or analytical methods. Empirical methods are regression models developed by employing empirical relationships between climatological variables and ET measurements. The general theory of empirical methods relates the daily ET to daily net radiation (Rn) and difference between instantaneous land surface temperature and air temperature (T_s - T_a) measured at a reference height near midday over diverse surfaces with variable vegetation cover.

The FAO Penman-Monteith method is a physically-based analytical approach derived from the Penman-Monteith equation [28, 29] a combination of the energy balance and mass transfer method, specifying the resistance factors of the reference surface. For more than a decade, this method has been considered as a universal standard to estimate ET_o. The main drawback with this method is it considers many parameters related to the evapotranspiration process; net radiation, air temperature, vapor pressure deficit, and wind speed etc. Which is not always possible to have all the necessary data for its application [30].

The Priestley-Taylor method for the estimation of $ET_0$is a rapid method with less data requirement compared to Penman-Monteith equation, the aerodynamic term of Penman-Monteith equation by a dimensionless empirical multiplier. Blaney–Criddle equation is a simple method for calculation of evapotranspiration. Blaney–Criddle equation is recommended for periods of one month or more period as it gives moderate accuracy by providing a rough estimate or "order of magnitude" only. Blaney-Criddle method is inaccurate or not suitable under extreme climatic conditions [31]. The Samani and Hargreaves method is a temperature-based empirical approach [32]. It was developed from the Christiansen equation (1968), which uses a multiplicative method to relate ET to solar radiation, relative humidity, temperature and wind speed, respectively. A case study for a wide range of climates in Iranrevealed that the spatial patterns of ET_o computed with Hargreaves–Samani and FAO-PM temperature methodswere found to be identical [33]. Makkink method is a radiation-based empirical approach to estimate ETo [34, 35]. It was first proposed by Makkink (1957) for grass ET estimation, which empirically related grass ET to global radiation as well as other climatic coefficients.

Computer models or calculation of Evapotranspiration includes CRIWAR, CROPWAT, AQUACROP etc. CRIWAR calculates the crop irrigation water requirements of a cropping pattern in an irrigated area. The input data are organized through three files: a general data file on the irrigated area, a meteorological data file, and a cropping pattern file. The cropping pattern file can be composed of 50 CRIWAR programmed crops and of any user-defined crop [36]. CROPWAT for Windows is a computer program for the calculation of crop water requirements and irrigation requirements based on soil, climate and crop data. In addition, the program allows the development of irrigation schedules for different management conditions and the calculation of scheme water supply for varying crop patterns (FAO). CLIMWAT is a climatic database to be used in combination with the computer program CROPWAT. and allows the calculation of crop water requirements, irrigation supply and irrigation scheduling for various crops for a range of climatological stations worldwide. AquaCrop is the crop growth model developed by FAO to address food security and assess the effect of the environment and management on crop production. AquaCrop simulates the yield response of herbaceous crops to water and is particularly well suited to conditions in which water is a key limiting factor in crop production [37, 38].

Though all the above discussed methods give an accurate estimate of point data, it was difficult to acquire regional ET from dot ET calculated by meteorological station data. As a result, regional water-saving potentiality calculated by traditional method mainly involved the water-saving quantity of water withdrawal with high water use efficiency. Measuring ET by RS could break the limitation of transform from dot ET to regional ET. Extrapolation of ET rates from a point to an extensive big area reduces the exactness of the estimation. At a local or regional scale, the satellite or airborne image analysis utilizing remote sensing procedures is a useful strategy for building up the spatial variability of ET. Remote sensing could be a perfect tool of ET estimation due to the highly distributed nature of land cover and vegetation [15]. remote sensing has the capability of quantifying the vegetation characteristics including species type and moisture stress a broad area which effects the ET measurement, RS also provides an area-based estimation and also more accurate results compared to land methods.

ET estimation using satellites imagery was also coupled to few empirical methods to simplify the ET measurement and reduce the input data requirements. Microwave imagery is using intensively to measure surface moisture and temperature in order to minimize atmospheric effects on optical data (e.g. clouds in the images).

4. Surface Energy Balance Models for ET extraction

4.1 Surface Energy Balance

The net radiation is residual of the latent heat flux, soil heat flux and the sensible heat flux. At the land, air interface surface energy balance can be written in the form of equation as follows

$$R_n = G + H + \lambda ET \quad \text{or} \tag{2}$$

$$\lambda ET = R_n - G - H \tag{3}$$

where G is the soil heat flux (Wm^{-2}), H is the sensible heat flux (Wm^{-2}), and λET is the latent heat flux associated with ET (instantaneous value for the time of the satellite overpass, W/m^2).

Net Radiation (R_n)

R_n can be estimated from the sum of the difference between the incoming ($Rs\downarrow$) and the reflected outgoing shortwave solar radiation ($Rs\uparrow$) (0.15 to 5 µm), and the difference between the incoming atmospheric longwave radiation ($R_L\downarrow$) and the reflected and surface-emitted longwave radiation ($R_L\uparrow$). The radiation balance under steady atmospheric condition is

$$R_n = R_s\downarrow + R_s\uparrow + R_L\downarrow - R_L\uparrow \tag{4}$$

Where R_n is the net radiation (Wm^{-2}), $Rs\downarrow$ is the incoming short-wave radiation ($W\cdot m^{-2}$), and $Rs\uparrow$ is the outgoing short-wave radiation (Wm^{-2}), while $R_L\downarrow$ is the incoming long-wave radiation (Wm^{-2}), and $R_L\uparrow$ is the outgoing long-wave radiation (Wm^{-2}). Since R_n represents the source of energy that must be balanced by the thermodynamic equilibrium of the other terms (factors). The net short-wave radiation can be written as follows

$$\sum R_s = (1-\alpha)R_s\downarrow = (1-\alpha).(S_c \times cos\theta \times d_r \times \tau_a \tag{5}$$

Where α is the surface albedo, S_c is the solar constant (Wm^{-2}), θ is the solar incidence angle, dr is the relative Earth-Sun distance, and τ_a is the atmospheric transmissivity. The incoming long wave radiation is the downward thermal radiation flux from the atmosphere. The air emissivity can be estimated by a function of the water vapor, pressure, and temperature in the cloudless atmosphere

$$R_L\downarrow = e_{sky} \times \sigma \times T_a^4 \tag{6}$$

Where $e_{sky}$is the air emissivity, σ is the Stefan-Boltzmann constant ($Wm^{-2}\cdot K^{-4}$), and T_a is the air temperature (K). The outgoing long-wave radiation is computed by using the Stefan-Boltzmann equation:

$$R_L\uparrow = \varepsilon_0 \times \sigma \times T_s^4 \tag{7}$$

where ε_0 is the surface emissivity and T_s is the surface temperature (K).

Sensible Heat Flux (H)

The sensible heat flux (H) is the rate of heat loss to the air by convection and conduction due to a temperature difference, which can be written as:

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

Where ρ_{air} is the density of air (kgm^{-3}), $C_p$is the air specific heat (=1004 J $kg^{-1}K^{-1}$), while dT is the difference between the air temperature and the aerodynamic temperature near the surface, ($dT = T_a - T_s$), calculated as set out in the SEBAL and r_{ah} is the aerodynamic resistance.

Soil heat flux (G)

Soil heat flux G is given by [26] through an empirical relation as

$G/R_n = T_s/\alpha(0.0038\alpha + 0.0074\alpha^2)(1 - 0.98NDVI^4)$ (9)

Where, αis albedo, Ts is surface temperature in K.

Latent Heat Flux (LE)

The rate of loss of latent heat from the surface due to evapotranspiration is Latent heat flux. According to the Equation (10), the latent heat can be written as:

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

4.2 Remote Sensing based Surface Energy based Algorithms:

Remote sensing-based evapotranspiration (ET) algorithms developed in recent years are well suited for estimating evapotranspiration and its spatial trends over time. Several methods have been developed to derive surface fluxes from RS observations, such as Surface Energy Balance Index (SEBI), two-source energy balance (TSEB) [9, 39] Simplified Surface Energy Balance Index (S-SEBI); [40] surface energy balance system (SEBS); [41, 42] SEBAL [43, 44] Mapping Evapotranspiration at High Resolution and with Internalized Calibration (METRIC) [45, 48].

Surface Energy Balance Index (SEBI) method is proposed by [49] for derivation of the evapotranspiration based on the contrast between dry and wet regions from evaporative fraction. This approach considers the Crop Water Stress Index (CWSI). In this methodology, relative evaporation is controlled by scaling a watched surface temperature in a greatest and least surface temperatures range. Signified by limits in the surface energy balance suggesting a theoretical lower and upper bound on the surface and air temperature difference [50]. The main distinction between SEBI and SEBAL are the differences in definition, calculation, and interpolation of maximum and minimum latent heat fluxes for a given set of 5 layers [51, 15].

A rearranged new technique from SEBI, called Simplified Surface Energy Balance Index (S-SEBI), has been developed by [40] to assess the surface flux from remote sensing information. To partition available energy into sensible and latent heat fluxes, main base is reflectance (albedo) dependent greatest and least surface temperature for dry and wet conditions (Figure 2) respectively. The results from different studies suggested that the spatial distribution of daily evapotranspiration could be derived fair accurately using the S-SEBI model that takes the spatial heterogeneity of near-surface air temperature into account [52, 54]. The advantage of this method is when the surface extremes are available, no extra climatological data is required.

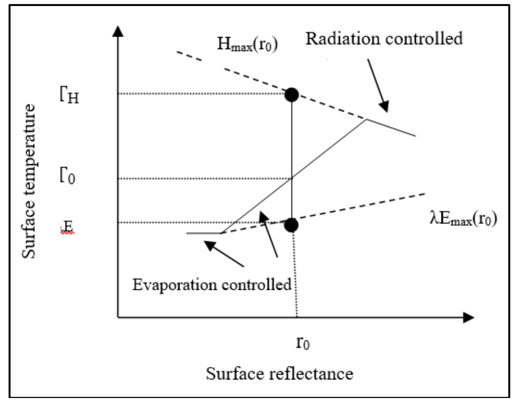

Fig 2: Schematic representation between surface reflectance and temperature. [52]

Su *et al.* [55] portrayed **Surface Energy Balance System (**SEBS) is a modification of SEBI for the estimation surface energy balance from remote sensing data. It is another well-known model for estimation of sensible and latent heat fluxes from satellite data and meteorological data. Calculations of land surface physical parameters, calculation of roughness length for heat transfer, and estimation of the evaporative fraction based on energy balance at limiting cases are the main bases of SEBS (Figure 3). SEBS has been widely applied over large heterogeneous areas [55-59]. The outcomes demonstrated the potential helpfulness of SEBS approach in evaluating surface heat flux from space for information assimilation purpose. Every day, month and yearly estimation of evapotranspiration in a semiarid condition have been estimated by SEBS. Accuracy of ET value estimated from SEBS could reach 10%–15% of that of *in-situ* measurements even when evaporative fraction ranged from 0.5 to 0.9 [58]. In any case, if the data is not readily available or moderately complex solution of the turbulent heat fluxes and more need of surface parameters can often cause more or less inconvenience [59, 60]. Due to known model sensitivities, there are discrepancies in the reported accuracy of the SEBS model and it is more suitable for 1-km to regional spatial scale [61].

Senay *et al.* [66] developed an enhanced version of the Simplified Surface Energy Balance (SSEB) model and to evaluate its performance using the established METRIC model. They claimed that SSEB can be used to estimate ET with inputs of surface temperature, NDVI, DEM, and reference ET [15].

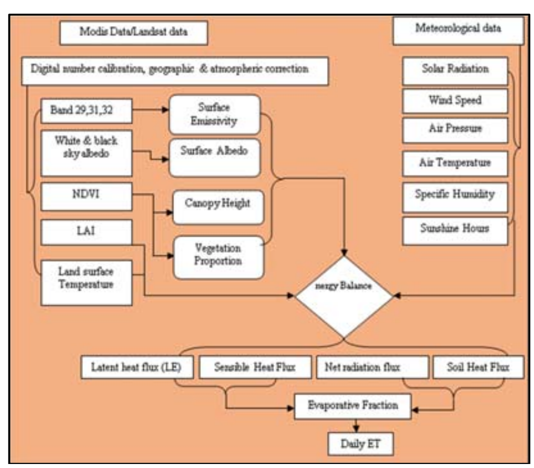

Fig 3: Flow chart for estimation of Evapotranspiration SEBS Algorithm

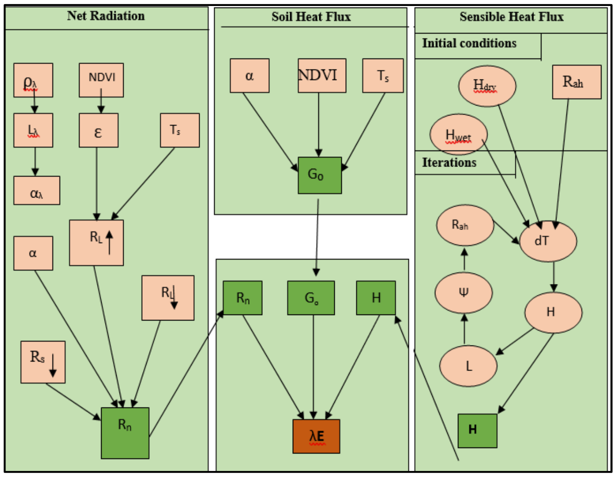

Fig 4: Algorithm for estimation of Actual Evapotranspiration using SEBAL algorithm.

The **Surface Energy Balance Algorithm for Land (SEBAL)** is one of several remote sensing-based crop evapotranspiration (ET) models. SEBAL is a method based on image processing that includes sub models in order to measure evapotranspiration as the remaining land surface energy balance. The theoretical and computational basis of SEBAL is applied in the Netherlands and the method is described in [44, 63, 64]. SEBAL considers groups of dry or wet pixels in the study area. At dry pixels, the total available energy is transforms into sensible heat flux therefore the latent heat is assumed to be zero. At wet pixels, surface temperature is equal to air temperature therefore sensible heat flux is theorized to zero. One advantage that SEBAL has is its minimal requirement for ground-based weather data. However, its downside is that in the presence of advection it may underestimate ET. This is due to the use of a fixed evaporative fraction (EF) for the entire day. The EF value is used to extrapolate instantaneous ET to daily ET values, based on the assumption that EF at the time of satellite overpass is the same (remains constant) as for the rest of the day, and therefore can be used to estimate daily ET [65, 66].

For calculation of H, two reference air temperatures are taken as an air temperature located at close to the surface and the other at an upper height. The difference in temperature dT for each pixel, SEBAL assumes the existence of a linear relationship between dT and surface temperature $T_s$as

$$dT = aT_s+b \quad (11)$$

where dT is the near-surface air temperature difference, Ts is the surface temperature, and "a" and "b" are coefficients for a given satellite image. The anchor pixels within the image represent extreme evaporative conditions. at cold pixel, dT and sensible heat flux are assumed to be near zero (H) (maximum evaporation). At a hot pixel where evaporation is near zero, all the available energy is modified essentially into sensible heat. In SEBAL, the cold pixel is generally taken from a pixel located in deep water, and the hot pixel is taken from a pixel located in an area that shows high surface temperature. Identifying the dry pixels is the most important aspect. Finally, H is obtained iteratively with γ_a dry corrected for stability.

The reported accuracy of SEBAL model in estimating ET under different climate conditions in both scales of farm and region has been studied. The common accuracy in farm scale increases 85% per day and up to 95% in a season and the ET yearly accuracy for large regions was averagely 96% [67]. It was also found that any prior knowledge about the crops, their types and cropping seasons is not required for the estimation of actual ET by SEBAL model [68]. The cost-savings and time-savings are apparent due to the decrease in input data required for simulating large-scale irrigation areas [69].

SEBAL has several drawbacks like, to estimate the model parameters a and b, subjective specifications of representative hot/dry and wet/cool pixels within the image are required [70]. Change in the extreme pixels selection, the resulting ET estimation also changes; Over mountainous regions, some adjustments are required based on a digital elevation model for Ts and u to account for the lapse rate [71] Errors in surface air temperature differences or surface temperature measurements greatly affects the estimated H.

Mapping evapotranspiration at high Resolution with Internalized activity (METRIC) developed in the European country as a variant of SEBAL. METRIC tool allows image-processing for mapping regional ET over difficult surfaces as a residual of the energy balance at the Earth's surface [72]. METRIC has been extended from SEBAL by integrating with reference ET computed from ground-based weather knowledge. The METRIC is based on the principle of evaporating liquid drops absorbs heat [46] to derive ET from remote sensing images in visible, near-infrared, and thermal infrared spectral regions in conjunction with ground-based wind and surface temperature measurement. Two anchor conditions are selected within an observed image to internally calibrate the sensible and latent heat flux computation and to fix boundary conditions for the energy balance. The high potential for successful ET estimates of SEBAL/METRIC models by comparing the derived ET with lysimeter measured values was reported by many studies [73,75]. At wet pixel, METRIC does not assume Hwet = 0 or LEwet = (Rn − G). ET is zero and 1.05ETr at hot and wet pixels, respectively. ETr reference ET calculated for rass crop using the standardized ASCE Penman- Monteith equation. In METRIC, wet pixels are selected in an agricultural field. The interpolation (extrapolation) of instantaneous ET to daily value of alfalfa ETrF is used instead of the actual evaporative fraction.

The ET estimates from these models are not deterministic [76]. The proper selection of the cold and hot pixels that satisfy the assumptions of the models so that the linear correlation between the near surface temperature difference and remotely sensed surface temperature holds good is important in SEBAL/METRIC. However, there is no particular criteria to select how large extent of a study site of interest would be appropriate, In few cases, existence of both hot and wet extremes may not exist. For example, no hot pixel from a large homogeneous forest. Also, there is no other alternative for the SEBAL models to automatic selection of extreme pixels from images with varying extents, spatial resolutions, and clouds. Basin or field (operational scale) Generally based on Landsat—daily, weekly, monthly at 30 m scale. METRIC-Landsat-ET at high (30 m) spatial resolution and daily to monthly resolution. METRIC provides daily, weekly, monthly ET -30 m pixel resolution. SEBAL provides daily, weekly, monthly ET -30 m pixel resolution. SSEB provides: daily, weekly, monthly ET -30 m pixel resolution. METRIC model was sensible to wind speed values at the time of satellite overpass [77]. Rangaswamy *et al* [78] stated that the METRIC algorithm was observed to perform better in full canopy conditions compared to partial canopy conditions. On average, the METRIC algorithm overestimated the hourly ET by 6.6% in comparison to the EC measurements; however, the daily ET was underestimated by 4.2%.

Duel-source model or Two-Source Models (TSM) was proposed by [79] to improve the accuracy of latent heat estimates using satellite remote sensing data, especially over sparse surfaces. The model was based on the principle of sensible and latent heat fluxes are transferred to the atmosphere from soil and vegetation components. Dispensability of ground-based information or any priori calibration has made the applicability of duel source model wider without resorting to any additional input data [76]. In the duel source model, Canopy latent heat flux is computed using the Priestley-Taylor equation. An iterative method is used to obtain the soil temperature and canopy temperature from satellite-derived Ts by assuming an initial value of 1.3 for the α, Priestley-Taylor parameter [80, 81]. The main advantages of the duel source method is its dispensability of precise atmospheric corrections, emissivity estimations and high accuracy in sensor calibration. Coupling of the duel source models with planetary boundary layer eliminates the need of ground-based measurement of Ta [82] and, thus, is much better suitable to applications over large-scale regions than other algorithms [83]. Comparisons of the different remote sensing ET models reviewed above are summarized in Table 1

Table 1. Comparison of the different remote sensing ET models

SEBI
Input variables: Net radiation, land surface temperature, Soil heat flux, Temperature at atmospheric boundary layer, wind speed
Assumptions: ET_{dry} limit is 0
ET_{wet} limit is at a potential evaporation rate
Advantages: Relates LE to the effects of surface temperature and aerodynamic resistance
Disadvantages: Requires ground based meteorological variables
SEBS
Input variables: Air temperature, Net radiation, land surface temperature, Soil heat flux, wind speed, Measurement height of wind speed and air temperature
Assumptions: ET_{dry} limit is 0
ET_{wet} limit is at a potential evaporation rate
Advantages Uncertainty in SEBS from T_s and meteorological parameters can partially be solved
Roughness height for heat transfer is computed explicitly instead of using fixed values.
Disadvantages: Requires too many parameters;
Relatively complex derivation of turbulent heat fluxes.
S-SEBI
Input variables: Net radiation, land surface temperature, Soil heat flux, surface albedo
Assumptions: $(EF)_a=(T_H-T_s)/(T_H-T_{LE})$
$T_H = (LE)_{min}$
$T_{LE} = (LE)_{max}$
Advantages: Ground based meteorological variables are not required.
Disadvantages: Needs to calibrate for Extreme temperatures which are location specific
TSM
Input variables: Net radiation, Air temperature, canopy temperature, land surface temperature, Soil heat flux, Fractional vegetation cover, Leaf area index, wind speed, Measurement height of wind speed and air temperature
Assumptions: Priestly –Taylor equation uses, fluxes are parallel to each other;
Includes the view geometry;
Eliminates the need of empirical corrections
Disadvantages: Requires many ground-based measurements
SEBAL
Input variables: Net radiation, land surface temperature, Soil heat flux, Vegetation index, wind speed
Assumptions: $dT = aT_s + b$
ET_{dry} limit is 0
ET_{wet} is surface available energy
Advantages: Requires minimum ground-based measurements;
Automatic internal calibration can be done;
Exact atmospheric corrections are not required.
Disadvantages: Applicable well over plain surfaces;
Knowledge is required in the selection of anchor pixels
METRIC
Input variables: Net radiation, land surface temperature, Soil heat flux, Vegetation index, wind speed, Measurement height of wind speed and air temperature
Assumptions: ET_{hot} pixel is 0
LE_{wet} pixel = 1.05 ET_r
Advantages: It is applicable to mountainous surfaces where SEBAL is difficult to apply
Disadvantages: Like SEBAL difficult in determination of anchor pixels.
Wind factor should be consider and is very sensitive

Red (R) and Near Infrared (NIR) bands used to predict NDVI and LAI in inference methods to correlate with ET. These methods require ground-based calibration, but still more affordable than empirical and residual methods which needs detailed field measurements. Many studies have been conducted to find the correlation between crop coefficients and VI and particularly NDVI. However, Allen *et al* [45] found that the relationship between crop coefficients and VI exists but emphasizes that the specific relationship is not transferable. This is true particularly because of irrigation effects on soil moisture and water stress conditions [15].

Through there are excellent methods of remote sensing technologies for estimation of ET, there are so many drawbacks with the remote sensing ET estimation. Mainly, satellites providing high spatial resolution imagery with lower temporal frequency and vise versa causes simultaneous acquiring of high temporal and spatial resolution imagery. Clouds in satellite imagery creates errors in ET estimation. Larger time in acquiring the satellite imagery and ET estimation can make the method impractical in operational applications. Gap filling procedures and coupling models have shown some promises to resolve this issue [15]. surface temperature derived for most of the remote sensing models that are adopted to derive use Thermal Infrared (TIR) radiation data. Surface emissivity and atmospheric corrections affect the retrieval of surface temperature and thus affect the quality of the information extracted from remote measurements. High spectral resolution is one of the most promising ways for obtaining both surface temperature and emissivity. Estimation of the individual components of available energy (Rn − G) separately ignores diurnal variation and phase difference between the diurnal cycles leads to errors in the estimation of both short and long-wave components. Accuracy of some land surface parameters from remotely sensed data, such as surface temperature, LAI, vegetative coverage, plant height, etc., still needs to be improved in order to improve ultimately the accuracy of ET estimation [79]. The vegetation index model is suitable only to the regions where advection is not important and net radiation is a major controlling factor and useful at time scales of weeks to years, but is unable to capture ET at time scales of days or shorter.

5. Conclusion

In the view of food security for the growing population, the best management of water resources in agriculture is prime important. Large scale irrigation infrastructure projects, have synergetic impacts of providing water storage for irrigation and domestic, producing hydropower; but happens at the expense of downstream agro ecological systems and with social implications. The entire management of agricultural water depends on accurate estimation of ET. Extension or extrapolation of ET rates from single weather station to a region decreases the accuracy of the estimation, which in turn leads to error in water application. Analysis of satellite images using remote sensing techniques is a practical method for developing the spatial variation of ET at a regional scale [84]. Due to the high distribution of mixed vegetation, remote sensing could be an ideal technique of ET measurement.ET measurement by remote sensing provides an area-based estimation and also has the capability of quantifying vegetation characteristics and moisture status for a broad area. From the present review, it is seen that all the remote sensing based algorithms have its own advantages and disadvantages but are important tools for evapotranspiration estimation on a regional scale. The S-SEBI algorithm is an important tool to be applied in ET analysis of semi-arid regions, due its practicability to solve the energy balance and its processing is simpler than SEBAL algorithm which needs the solution of an iterative process [14]. The accuracy of SEBAL model in estimating ET under different climate conditions in both scales are given accurate results but do not accommodate the effect of variations in fractional vegetation cover on ET extremes. The SEBAL algorithm performance has been better than S-SEBI algorithm. The SEBAL algorithm shows better results in obtaining ET but needs the determination of difficult parameters. The SEBAL also has advantage like less ancillary ground data but over mountainous regions, some adjustments are required based on a digital elevation model for Ts and u. In METRIC model the limitation of SEBAL over mountainous areas are solved through integration with reference ET. From the discussions above, it is concluded that the SEBAL/METRIC models had high potential for successful ET estimates. Although remote sensing ET models can provide relatively accurate spatial distributions of instantaneous ET, it is usually only employed under clear sky conditions and at an instantaneous scale.

Despite sufficient progress, there is no universal model, which could be used throughout the world irrespective of the changes in land surface characteristics, in the climate and terrain without any modification or improvement to estimate the ET from satellite data and also lack of the land surface ET at satellite pixel scale for the truth validation is described in details in the above literature. With the consideration of detailed topics mentioned, Remote sensing ET estimation models provides very accurate data, which can be used in the assessment and analysis of the Water-Energy-Food Nexus. Such analysis can help to inform decision makers on how to respond to these issues, taking into account the diverse and multiple impacts these responses may have across sectors and over time.

6. References

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