Estimation of land surface variables using remote sensing and surface energy balance algorithm of land (SEBAL) in Gash Delta, Sudan

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Introduction

SEBAL is an energy balance model based on a satellite image-processing which is comprised of twenty-five computational sub-models that calculate evapotranspiration (ET) and other energy exchange at the earth surface. Application of SEBAL is an efficient, accurate and inexpensive procedure to predict actual evapotranspiration fluxes from irrigated land throughout the growing season (Allen *et al*., 2001). SEBAL represents an emerging technology that has the potential to become widely adopted and used by the world's water resources communities. Evapotranspiration maps created using SEBAL will be routinely used as input to daily and monthly operational and planning models for ground-water management, irrigation water supply planning, and hydrologic studies (Allen *et al*., 2005).

In this study, the land surface variables specifically NDVI, albedo, temperature and land surface heat flux (net radiation and soil heat flux) in Gash Delta, Eastern Sudan were estimated by using a satellite image of Landsat-5 TM and SEBAL.

Study area and dataset

Gash Delta is lying between latitudes 15° 15′ – 16° 15′ N and longitudes 36° 05′ – 36° 30′ E, Eastern Sudan. Water flow occurs during autumn season (July – October). The total arable land of Gash Delta is about 315,000 ha and only 50% is under use. The irrigation network area is 105,000 ha. The irrigation system of the Delta consists of major intakes and canals system: Fata, Salaam Aleikum, Mekali, Tendylai, Metateib and Hadalya.

In this study, Landsat-5 TM image of 9/11/2009 was used to calculate surface variables. ERDAS Imagine was used to process the image.

Fig. 1 The location of study area

Estimation of land surface variables using SEBAL

Surface albedo (α): Surface albedo is defined as the ratio of the reflected radiation to the incident shortwave radiation. Surface albedo is computed by correction of the α_{toa} for atmospheric transmissivity:

$$\alpha = \frac{\alpha_{toa} - \alpha_{path\_radiance}}{\tau_{sw}^2} \qquad (1)$$

where, α_{toa} is the albedo at the top of the atmosphere, $\alpha_{path\_radiance}$ is the average portion of the incoming solar radiation across all band that is back-scattered to the satellite before it reaches the earth's surface and τ_{sw} is the atmospheric transmissivity.

Normalized difference vegetation index (NDVI): NDVI is the ratio of the differences in reflectivities for the near-infrared band (ρ_4) and the red band (ρ_3) to their sum:

$$NDVI = \frac{\rho_4 - \rho_3}{\rho_4 + \rho_3} \qquad (2)$$

where, ρ_4 and ρ_3 are reflectivities for bands 4 and 3.

Surface temperature T_s: Surface temperature is computed using the following modified Plank equation:

$$T_s = K_2 \Big/ \ln\left(\frac{K_1}{L_\lambda + 1}\right) \qquad (3)$$

where, L_λ is the spectral radiance in (W/m^2/sr/μm). K_1 and K_2 are constants for Landsat images.

Net radiation (R_n): Net radiation at the earth's surface is a result of the combination of incoming and outgoing solar radiation, both in the short wave as in the long wave part of the solar energy spectrum. It is given by the surface radiation balance equation:

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$$R_n = (1-\alpha)R_{S\downarrow} + R_{L\downarrow} - R_{L\uparrow} - (1-\varepsilon_0)R_{L\downarrow} \quad (4)$$

where, $R_{S\downarrow}$ is incoming shortwave radiation (Wm^{-2}). α is the surface albedo (dimensionless). $R_{L\downarrow}$ is incoming long wave radiation (Wm^{-2}). $R_{L\uparrow}$ is outgoing long wave radiation (Wm^{-2}). ε_0 is the surface thermal emissivity (dimensionless).

Soil heat flux (G_0): Soil heat flux is the rate of heat storage into the soil and vegetation due to conduction. Consequently, it is computed according to the following equation:

$$G_0 = R_n\left[\frac{(T_s - 273.16)}{\alpha}\cdot(0.0038\alpha + 0.0074\alpha^2)\cdot(1-0.98NDVI^4)\right] \quad (5)$$

where, G_0 is the soil heat flux (Wm^{-2}). R_n is the net radiation (Wm^{-2}). T_s is the surface temperature (K). α is the surface albedo. *NDVI* is the normalized difference vegetation index.

Results and Discussions

Table 1 shows the values of NDVI range between 0.07 to 0.71, surface albedo range between 0.15 to 0.45 and surface temperature range between 302.33 to 320.18 (K). The areas which have low surface albedo and low surface temperature have high vegetation index, the other areas which have low vegetation indices tend to have high surface albedo and high surface temperature. It has been found in previous researches that the standard surface albedo for some cereal crops such as maize is ranging between 0.14 to 0.22, therefore, the large range shown in this study might be due to shifting cultivation system practiced in Gash Delta in which the cultivated area has the normal albedo, while the none cultivated area has relatively large albedo.

The values of land surface heat flux; net radiation and soil heat flux were from 223.74 to 480.32 (Wm^{-2}) and from 50 to 84 (Wm^{-2}) respectively. The areas with high vegetation index have high net radiation and areas with low vegetation index have low net radiation, on other hand, areas with high vegetation index have low soil heat flux and areas with low vegetation index have high soil heat flux.

Fig. 2 shows a distribution map of net radiation using different colors level, the green one indicates the high value of net radiation, whereas, the red indicates the lowest. In the cultivation system practiced in Gash Delta, the land is divided into several blocks and each block divided into a number of Misga which occupies about 840 ha. In crop growing season annually, some Misgas are cultivated while others are not by using shifting system. Based on what is mentioned above, it can be clearly observed that the high value of net radiation (green color) resulted from the cultivated and vegetated land, while the low value of net radiation (red color) resulted from the fallow land with large albedo.

Table 1 Surface parameter and land surface heat flux values

Surface variables	Statistics information			
	Max	Min	Mean	Std. Dev.
NDVI	0.71	0.07	0.20	0.13
Albedo	0.45	0.15	0.31	0.05
T_S (K)	320.18	302.33	313.99	2.9
R_n (Wm^{-2})	480.32	223.74	318.25	46.8
G_0 (Wm^{-2})	84.0	50.0	76.9	4.0

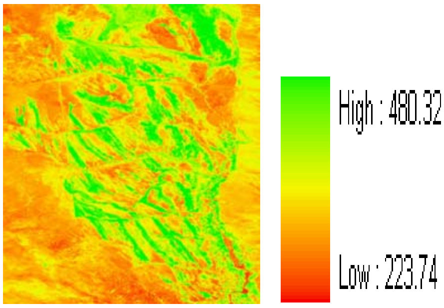

Fig. 2 Distribution map of net radiation

Conclusion

The study has demonstrated the feasibility of remote sensing and SEBAL to estimate surface parameters and surface land heat fluxes in Gash Delta such as NDVI, surface albedo, surface temperature, net radiation and soil heat flux. The accuracy of estimated values should be discussed in future investigations.

References

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