THE SPATIAL ANALYSIS OF SURFACE TEMPERATURE AND EVAPOTRANSPIRATION FOR SOME LAND USE/COVER TYPES IN THE GEZIRA AREA, SUDAN

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KEY WORDS: Landsat7, Land Cover, NDVI, Surface Temperature, Evapotranspiration, SEBAL, Gezira Scheme

ABSTRACT:

In this study Landsat Enhanced Thematic Mapper Plus (ETM+) images (Row/Path:173/50) acquired on September 6, 2001 and November 28, 2002 were analyzed together with the aid of additional ancillary data to investigate the spatial distribution property of land surface temperature (LST) and evapotranspiration (ET) over the Gezira area. Images in visible, near infrared and thermal infrared regions of the electromagnetic spectrum were processed to extract surface radiant temperature, Normalized Differenced Vegetation Index (NDVI), and land cover types. SEBAL model was used to estimate evapotranspiration; the processing of the model was done after the standard procedure described in Bastiaanssen (1995). The results of the regression between extracted land surface temperature, NDVI and evapotranspiration show negative (-) correlation. The results demonstrate that LST possessed a slightly stronger negative correlation with the ET than with NDVI for all land cover types. The distribution of LST in the context of different land use/cover types was also investigated in this paper. On the other hand the daily average evapotranspiration derived by SEBAL model for sorghum field at the Gezira Research Station Farm (GRSF) for Sep.6, 2001 and Nov.28, 2002 images are 4.5 and 2.8 mm/day respectively.

ZUSAMMENFASSUNG:

In dieser Studie von “Landsat Enhanced Thematic Mapper Plus” (ETM+) Bilder (Row/Path:173/50), die am 06 September 2001 und 28 November 2002 gemacht wurden, wurden mit der Hilfe von zusätzlichen Daten analysiert um die räumliche Verteilungseigenschaft der Temperatur der Landoberfläche (LST) und Verdampfung (ET) über dem Gezira Bereich zu untersuchen. Bilder im sichtbaren, nahen Infrarot- und thermal Infrarot-Bereich des elektromagnetischen Spektrums wurden bearbeitet zur Extraktion der Oberflächen-Strahlungs-Temperatur, Nomarisierter Differenz Vegetation Index (NDVI) und des Landbedeckungstyps. Zur Schätzung der Verdampfung wurde einen SEBAL Modell verwendet; Die Bearbeitung des Modells wurde nach in Bastiaanssen (1995) beschriebener normaler Prozedur durchgeführt. Die Ergebnisse aus der Regression zwischen extrahierte Temperatur der Landoberfläche, NDVI und Verdampfung zeigen negative (-) Korrelationen. Die Ergebnisse zeigen, dass LST eine etwas stärkere negative Korrelation mit ET als mit NDVI für alle Bedeckungstypen aufweist. In der Abhandlung wurde auch die Verteilung der LST, die auf verschiedene Landnutzungen /Bedeckungstypen Bezug hat, untersucht. Andererseits ist die tägliche mittlere Verdampfung, die durch das SEBAL Modell für Mohrenfelder an der “Gezira Research Station Farm (GRSF)” aus den Bildern vom 06 September 2001 und 28 November ermittelt wurde, 4.5 bzw. 2.8 mm/Tag.

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1. INTRODUCTION

Urban climate studies have long been concerned about the magnitude of the difference in observed ambient air temperature between cities and their surrounding rural regions, which collectively described the urban heat island effect (Landsberg, 1981). The aim of analyzing and comparing surface temperature differences in urban areas among different land cover types using landsat thermal infrared imagery depicts the significance of understanding the impacts of urbanization on climate and over all environmental change. For this study area the bulk of urban areas are located inside the irrigated scheme and has the possibilities of expansion in all directions, it is increasing in population and in area, moreover the sand encroachment in northern and western parts of the scheme threaten the adjacent agricultural and non-urban lands.

Research on LST shows that the partitioning of sensible and latent heat (λET) fluxes and thus surface temperature response a function of varying surface soil water content and vegetation cover (Owen et al. 1998). A higher level of λET exchange was found with more vegetated areas, while sensible heat exchange was favored by sparsely vegetated such as urban areas (Oke, 1982). This finding encourages more scholars to focus on the relationship between LST and different vegetation indices.

The relationship between LST and vegetation indices, such as NDVI, has been extensively documented in the literature. The basis for using NDVI in LST estimation is the amount of vegetation present is an important factor, Boone et al. (2000) mentioned that NDVI can be used as an indicator of relative biomass and greenness. Many scientists concluded that the slope of the LST-NDVI curve has been related to soil moisture content and the evapotranspiration of the surface.

Surface temperature is the basic parameter for the deviation of the thermal behavior of the environment. It can be daily estimated from different satellite sensors using thermal infrared measurements. The landsat7 satellite, which was launched in April 1999, carries the ETM+ sensor with eight bands. The spatial resolution of the ETM+ sensor are 15m in the panchromatic band, 30m in the visible, near and shortwave infrared bands, and 60m in the thermal infrared bands. The increased spatial resolution of the thermal infrared bands makes it possible to do more detailed analysis of the urban and rural microclimate.

The objectives of this study are:

1. To derive land surface temperatures and analyze their spatial distribution using TIR of landsat7.
2. To investigate the relationship between LST, NDVI and estimated evapotranspiration.
3. To analyze the LST distribution properties patterns in the context of present land use/cover types.

2. METHODOLGY

2.1 Extraction of Evapotranspiration

The surface energy balance for land (SEBAL) was used to estimate the evapotranspiration and other energy balance terms. In the SEBAL model ET was calculated from satellite images and local weather station data using surface energy balance equation. The processing of the SEBAL model was done after the standard method described in Bastiaanssen (1995).

The geographical and atmospheric rectified images were processed with multi-spectral analysis to obtain the initial maps such as, NDVI, surface temperature, albedo and radiative/conductive/convective energy fluxes at the soil surface. For insight of the practical procedure, Tasumi et al. (2000), provide extensive details of step-by-step considerations applied.

Calculation of the net radiation (Rn) and soil heat flux (G) were done according to the procedure described by Bastiaanssen (1995). The sensible heat flux is expressed using a bulk resistance approach. The calculation requires three other parameters such as, roughness for momentum, wind speed and the difference between surface (Ts) and air temperature (Ta) which is given by Eq. 1.

$$T_s - T_a = aT_s + \mathrm{b} \qquad (1)$$

The spatial distribution of dT (Ts – Ta) is calibrated inverting the sensible heat flux over both wet areas (Ts – Ta ~ 0) and dry areas (Rn – G ~ H). These areas are selected considering respectively the minimum and maximum temperature over the study area. Bastiaanssen et al. (1998) emphasized that this differential approach reduces the consequences of aerodynamic temperature inaccuracy on sensible heat flux estimation. Finally the latent heat flux is computed as surface energy budget residue (Eq. 2).

$$\lambda ET(x,y) = Rn(x,y) - G(x,y) - H(x,y) \qquad (2)$$

where λET = latent heat flux,
Rn = surface net radiation,
G = soil heat flux,
H = sensible heat flux,
x, y = image coordinates.

The Rn is positive when directed toward the surface and G, H, λET, are positive when directed away from the surface.

The daily evapotranspiration was calculated for the entire images by considering the evaporative fraction (Λ) {Λ = λET/ (Rn – G)} and 24 hour net radiation, the calculation of the ETa includes the transformation of Rn_{24hour} from W/m^2 to mm per day by the surface temperature dependent latent heat of vaporization. Background theory and details of SEBAL is described in Bastiaanssen et al. (1998).

2.2 Extraction of Land Surface Temperature

Surface temperature is an important parameter in understanding the exchange of energy between the earth surface and the environment. The surface temperatures were derived from the TIR band radiance values of ETM+ sensor. The local time of satellite overpass was in the midmorning (approximately 10:58 AM). The surface temperatures were extracted using the simplified plank function (Eq. 3) (Markham and Barker, 1986):

$$T = \frac{k_2}{\ln\left(\frac{k_1}{L_\lambda + 1}\right)} \qquad (3)$$

where T = effective at-satellite temperature in k
L_λ = spectral radiance in W/(m^2 ster μm)
k_2 and k_1 = pre-launch calibration constant

For landsat7 ETM+ k_2 and k_1 are 1282.71 W/ (m^2 ster μm) and 666.09 respectively. L_λ value for landsat7 ETM+ was calculated according to (NASA, 2002):

$$L_\lambda = (L_{max} - L_{min}) * QCAL / 255 + L_{min} \quad (4)$$

where L_{max}= maximum spectral radiance in (W/m^2 ster µm) at QCAL equal 0 DN

L_{min} = minimum spectral radiance in (W/m^2 ster µm) at QCAL equal 255 DN

QCAL = the quantized calibrated pixel value in DN

L_{min} and L_{max} are post-launch values specific to low (6L) and high (6H) gain version of the thermal band on ETM+. In this paper, L_{min} and L_{max} are 0 and 17.04 W/ (m^2 ster µm) respectively.

The ETM+ images were corrected for emissivity differences accordingly to the different land cover types using the NDVI and albedo values. The aforementioned equations were incorporated into a spatial modeler in ERDAS IMAGINE to obtain surface temperature maps.

2.3 Extraction of NDVI

The Normalized Difference Vegetation Index (NDVI) (Rouse et al. 1974) can be used as an indicator of relative biomass and greenness. It was computed from the visible (0.63 – 0.69µm) and near infrared (NIR) (0.76 – 0.90µm) bands of the ETM+ images (Eq. 5). The original vegetation activity has the values between -1 and +1, but in this study it was transformed into images of 8bit (0 – 255) value.

$$NDVI = \left(\frac{(NIR - Red)}{(NIR + Red)} \right) \quad (5)$$

where NIR = near infrared reflectance (band 4)

Red = Red reflectance (band 3).

3. RESULTS AND DISCUSSION

3.1 Correlation Analysis of LST vs. NDVI

Tables 1 & 2 show the relationship between the land surface temperature and NDVI values for some land use/cover types in the Gezira scheme, Sudan.

Land use type	Regression Equation	R	R^2
Urban	Y=-0.1459x+325.2	-0.79	0.635
Suburban	Y=-0.0758x+317.4	-0.24	0.0579
Agric. Area	Y=-0.0473x+309.9	-0.89	0.805
Sand dune	Y=-0.1018x+325.1	-0.78	0.601

Table 1. Correlation analysis of LST vs. NDVI September 6, 2001

It is clear from the two tables that the results of the correlation and regression analysis between land surface temperature and NDVI for different land use/cover types possessed negative (-) correlation for different image dates

The highest negative correlation was found in agriculture field, while the lowest correlation was observed in sand dune area. The results also revealed that agricultural areas show the lowest surface temperature and the highest NDVI; this could be attributed to the fact that the increase in green biomass is often associated with a reduction in surface resistance to evapotranspiration, greater transpiration and larger latent heat transfer resulting in lower surface temperature.

Land use type	Regression Equation	R	R^2
Urban	Y=-0.2211x+345.2	-0.74	0.55
Suburban	Y=-0.1615x+338.2	-0.73	0.54
Agric. area	Y=-0.1564x+334.7	-.092	0.85
Sand dune	Y=-0.0602x+311.6	-0.21	0.05

Table 2. Correlation analysis of LST vs. NDVI November 28, 2002

3.2 Correlation Analysis of LST vs. ET

Table 3 & 4 show the relationship between LST and evapotranspiration for different land use types in the study area, such as urban, suburban, and agricultural area.

Land use type	Regression Equation	R	R^2
Urban	Y=-0.4071x+126.9	-0.89	0.804
Suburban	Y=-0.3838x+120.1	-0.92	0.847
Agric. area	Y=-0.1913x+61.89	-0.95	0.894

Table 3. Correlation analysis of LST vs. evapotranspiration September 6, 2001

The spatial distribution characteristics of land surface temperature according to evapotranspiration estimated by SEBAL shows negative correlation. The results identified that agricultural area obtained the highest correlation followed by suburban and urban land use types. It can be concluded that LST/ET slopes were stronger than LST/NDVI slopes.

Land use type	Regression Equation	R	R^2
Urban	Y=-0.2022x+64.5	-0.89	0.782
Suburban	Y=-0.3085x+98.2	-0.94	0.885
Agric. area	Y=-0.2396x+76.3	-0.99	0.982

Table 4. Correlation analysis of LST vs. evapotranspiration November 28, 2002

3.3 Analysis of LST, NDVI and ET by Land Use Patterns

Figure 5 represents the distribution of land surface temperature in terms of different land use/ cover types. Table 6 shows the mean land surface temperature, NDVI, and ET for four land use/cover types. It is clear from Figure 5 that water has the lowest surface temperature followed by agricultural area, suburban and urban while the sand dune scored the highest surface temperature.

Table 6 indicates that agricultural area in both image dates scored the lowest surface temperature, and highest evapotranspiration and NDVI; this could be due to the fact that the vegetation areas reduce the surface resistance of evapotranspiration which resulted in low surface temperature. The highest LST was observed in sand dune area where the evapotranspiration tends to zero due to the absence of vegetation, this was followed by urban and suburban land use types.

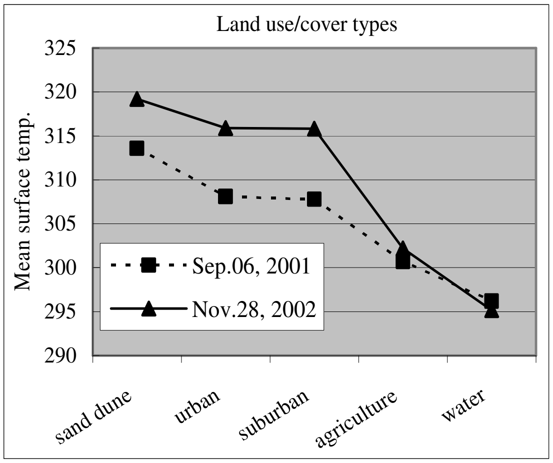

Figure 5. Thermal signature (k) of land use/cover types for Sep. 2001 and Nov. 2002 images

September 6, 2001				
Land use Parameter	Sand dune	Urban	Suburban	Agric. area
LST (k)	313.6	308.1	307.8	300.7
ET mm/d	0.0	1.51	1.94	4.36
NDVI	113.6	117.3	127	194.3
November 28, 2002				
LST (k)	319.2	315.9	315.8	302.2
ET mm/d	0.0	0.66	0.71	3.92
NDVI	125.4	132.5	138.1	207.7

Table 6. The extracted mean land surface temperature, ET and NDVI for different land use/cover types

3.4 Extraction of Energy Balance and ET

Surface energy balance algorithm for land (SEBAL) was used to estimate the daily evapotranspiration and the different terms of surface energy balance at the time of satellite overpass. Table 7 shows the energy balance and daily ET for sorghum field at the Gezira research station farm (GRSF).

Flux (Wm^{-2})	Sep.6, 2001 x=552669 y=158933	Nov.28, 2002
Instantaneous Rn	617	462
Instantaneous G	176	135
Instantaneous H	135	116
Instantaneous λET	306	211
Daily ET mm/day	4.5	2.8

Table 7. Instantaneous energy balance terms during satellite overpass for Sep.6, 2001 and Nov.28, 2002 in sorghum field at GRSF

It is clear from table 7 that the daily evapotranspiration is 4.5 mm/day and 2.8 for Sep.6, 2001 and Nov.28, 2002 respectively. The reduction of ET in Nov.28 could be due to the decrease in the available net radiation which coincides with the harvesting time of sorghum in the GRSF. The energy exchange over the sorghum field shows that the energy converted into latent heat flux in September (306 Wm^{-2}) was more than the energy converted in November (211 Wm^{-2}). This finding strongly supports the fact mentioned earlier by Oke, (1998).

4. CONCLUSIONS

In this study landsat7 ETM+ was used to analyze the spatial distribution of land surface temperature in terms of land use/cover types, NDVI and evapotranspiration. The daily ET was estimated using SEBAL model. The results of the correlation analysis between LST, NDVI and ET show negative (-) correlation for all land use types, the results also showed that LST/ET slopes were stronger than LST/NDVI slopes. The analysis indicated that water and agricultural field scored the lowest surface temperature followed by suburban, urban and sand dune. It is important to mention that the relationship between LST and NDVI was determined largely by vegetation and environmental conditions (e.g., vegetation biomass and soil moisture content) and was thus related to the partitioning of the energy fluxes. The LST/NDVI slopes were also affected by acquisition time over the season. The analysis of surface temperature-to-land use/cover types would help the decision maker for better future planning.

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ACKNOWLEDGEMENTS

This research is part of a study supported by the grants-in-aid (No.16405031) from the Japan Society for the Promotion of Science.