On the Relationship between Satellite-based Evapotranspiration and Normalized Difference Vegetation Index, Case Study: Narok County of Kenya

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ABSTRACT

This study sought to unearth a possible relationship between evapotranspiration and Normalized Difference vegetation index (NDVI). Daily datasets of Evapotranspiration with a pixel resolution of 3km were sourced from the EUMETSAT's Land Surface Analysis Satellite Application Facility (LSA-SAF). Twice monthly (NDVI) datasets were retrieved from the Moderate Resolution Imaging Spectro-radiometer (MODIS) which is housed by the TERRA satellite platform. The NDVI is at a pixel resolution of 250m. The two datasets were averaged accordingly using Climate Data Operators (CDO) to produce monthly values from January 2001 to October 2012. Using Grid Analysis and Display System (GrADs), data for a total of 36 grid locations were extracted from the two datasets at a uniform spatial increment of 0.1° covering an estimated area of 3600Km^2 within Narok County. Scatter plots showed that in most locations, there existed a positive linear relationship between the two datasets with 80% of the grid locations considered confirming this analogy. Pearson correlation analysis was performed between the two datasets. Only a few locations showed non-significant correlations at the 95% confidence level. The results therefore pointed to a conclusion that the two datasets can be used interchangeably for various agro-meteorological applications. However, the Root Mean Square Error (RMSE) computed between the two datasets for each of the considered grid locations was large. It's therefore advised that one should exercise caution in using the 2 datasets interchangeably. One of the factors that might have contributed to the error is the different spatial and temporal resolutions between the two datasets. NDVI had a pixel resolution of 250m while evapotranspiration had a resolution of 3km. At the same time, the temporal resolution for the NDVI data was twice monthly while evapotranspiration had a temporal resolution of 10 day averages.

Keywords: Grads, CDO, Pearson product moment correlation, Scatter plots NDVI, Evapotranpiration

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INTRODUCTION:

The need for, and the benefits of, data for various agrometeorological applications cannot be overemphasized [1,2]. For example, in order to closely monitor the vegetative areas, data on crop growth need to be available right from the sprouting level to maturity stages. Ground-based data on various meteorological parameters like rainfall, wind speed, humidity and temperature and agrometeorological data like the leaf-area index, evapotranspiration, evaporation, and vegetation greenery are absolutely important for the purposes of monitoring drought evolution all over the globe. However, ground-based meteorological and agro-meteorological stations are sparse in nature especially over Africa. To adequately represent spatial variations of greenery over a small area, the distance between 2 stations shouldn't be more than a few kilometers [1]. A possible solution to this would involve establishing many new agrometeorological stations. This would be very costly in terms of investment and operational costs.

The immediate solution to tackle the station distribution challenge is satellite data. Satellites have the capability of covering entire regions with sufficient spatial (3-5km grid size) and temporal resolution (1-hourly repetition) to adequately represent the variability of weather and crop conditions [1].

Vegetation indices are important tools in the monitoring, mapping and resource management of the Earth's terrestrial vegetation. They are radiometric measures of the amount, structure, and condition of vegetation. The Normalized Difference Vegetation Index, the Enhanced Vegetation Index, Evapotranspiration among many others are some of the vegetation indices used to characterise vegetation growth based on vegetation spectral reflectance [3,4]. Due to the increased demand for weather-based insurance policies [1], 2010), different vegetation indices need to be understood as well as their relationship with each other. This would create an alternative landing if for example one index is discontinued due to among other things, operational costs for keeping the instrument on board the satellite [1].

The Normalized Difference Vegetation Index is based on the earth surface reflection in the red (R) and Near Infrared (NIR) spectral band i.e. reflectances between 0.58μ to 0.68μ and 0.725μ to 1.1μ [5].
It's given by;

$$NDVI = \frac{NIR - R}{NIR + R} \text{ ………..…… (1)}$$

We therefore expect that plants would reflect less in the red due to absorption by Chrolophyll and reflect highly in the NIR due to low absorption and strong scattering. Thus we expect low reflectance from soil and rocks and high reflectance from green plants. Thus NDVI is used for monitoring vegetation canopy [1].

However, NDVI doesn't tell us about water availability in the plant system save for the greenery nature of vegetation. Evapotranspiration on the other hand gives more insight on water uptake in the plant system depending on the amount of water transpired to the atmosphere. Evapotranspiration data is computed through the Energy and Water Balance Monitoring System (EWBMS) of the Meteosat. The concept involves using hourly geostationary satellite data to create daily data field of surface and air temperature, surface albedo, global and net radiation, actual and potential evapotranspiration and precipitation. Calibration equations are applied to convert thermal infrared and visual digital values to planetary temperature (T_o) and planetary albedo (A). The boundary layer air temperature (T_b) is then computed using a regression between observed noon and midnight surface temperatures.

$$T_{12} = a . T_{24} + b \text{ ……..………….. (2)}$$

Coefficient a above is derived from regression and if regression is not accurate enough it’s derived on the basis of a model of the course of the daily surface temperature. Global radiation at noon is then computed and converted to a daily average value of the global radiation (I_g) using fourier analysis of the solar cycle. The upgoing thermal radiation flux (I_u) is estimated from the surface temperature and the downgoing radiation flux from the boundary layer air temperature (I_d). The net radiation (I_n) is then obtained with as follows;

$$I_n = (1 - A)I_g + I_d - I_u \text{ ....…… (3)}$$

The sensible heat flux into the atmosphere is then computed as follows;

$$H = \alpha(T_0 - T_b) \text{ ……………… (4)}$$

where alpha is the atmospheric heat transfer coefficient. With all these parameters, the Latent energy which is the energy used in evaporating the water can be calculated as;

$$LE = I_n - H \text{ ……..……… (5)}$$

From $LE\ (Wm^{-2})$ we can calculate the actual evaporation (E) in mm/day using the notion that about $28\,Wm^{-2}$ is required for evaporating 1 mm of water. If there is sufficient water for evaporation, then the evaporation is Potential evaporation (LE_p). From the Penmann-Monteith equation it can be shown that;

$$LE_p = 0.8\mathrm{I}_n \text{ ………………… (6)}$$

Relative evapotranspiration is the defined as;

$$RE = \frac{LE}{LE_p} \text{ ……………..…… (7)}$$

Enhanced vegetation index-a product being prepared and maintained by the MODIS science team-is more or less similar to the NDVI although designed to enhance the vegetation signal with improved sensitivity in high biomass regions and improved vegetation through a de-coupling of the canopy background signal and a reduction in atmosphere influences. It is more superior to NDVI due to its improved spatial resolution, less sensitive to soil and atmospheric effects and therefore more sensitive to differences in heavily vegetated areas [6].

$$EVI = G * \left\{ \frac{NIR - R}{NIR + C_1 R - C_2 B + L} \right\} \text{ … (8)}$$

where NIR, R, and B are atmospherically-corrected (or partially atmospherically-corrected) surface reflectances and C_1 and C_2 and L are aerosol resistance coefficients to correct for atmospheric condition (i.e. aerosol resistance) G is a gain factor and L is the canopy background adjustment that addresses nonlinear, differential NIR and red radiant transfer through canopy. The coefficients usually adopted for the EVI algorith, according to [7], are $L = 1, C_1 = 6, C_2 = 7.5$, and $G = 2.5$

2. AREA OF STUDY

The study area was Narok County in Kenya. The county is situated in the South-west of Kenya lying within 34.5E-36.5E and 2S-0.5S. Tourism and agriculture is the mainstay of the county with wheat and barley being grown for commercial purposes [7] (Sindiga 1999). Toursim as an economic activity in the county has rendered Narok one of the richest counties in Kenya with Maasai Mara being an international tourist destination.

36 grid locations selected for study in this particular study are given in table 1.

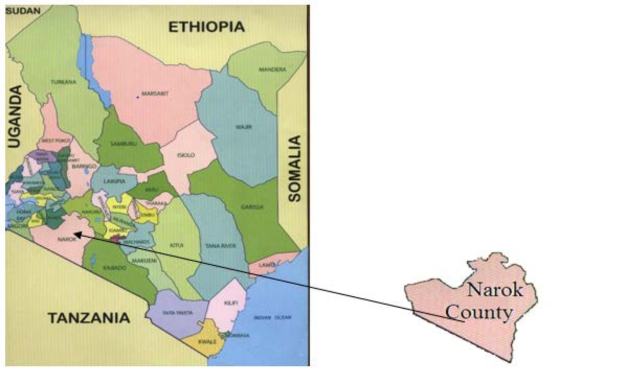

Figure 1a: Counties of Kenya Figure 1b: A map of Narok County

Table 1: Grid locations chosen for the study

Grid Location	Lon.	Lat.	Grid Location	Lon.	Lat.
Grid_1	35.5˚E	1˚S	Grid_19	35.8˚E	1˚S
Grid_2	35.5˚E	0.9˚S	Grid_20	35.8˚E	0.9˚S
Grid_3	35.5˚E	0.8˚S	Grid_21	35.8˚E	0.8˚S
Grid_4	35.5˚E	0.7˚S	Grid_22	35.8˚E	0.7˚S
Grid_5	35.5˚E	0.6˚S	Grid_23	35.8˚E	0.6˚S
Grid_6	35.5˚E	0.5˚S	Grid_24	35.8˚E	0.5˚S
Grid_7	35.6˚E	1˚S	Grid_25	35.9	1˚S
Grid_8	35.6˚E	0.9˚S	Grid_26	35.9	0.9˚S
Grid_9	35.6˚E	0.8˚S	Grid_27	35.9	0.8˚S
Grid_10	35.6˚E	0.7˚S	Grid_28	35.9	0.7˚S
Grid_11	35.6˚E	0.6˚S	Grid_29	35.9	0.6˚S
Grid_12	35.6˚E	0.5˚S	Grid_30	35.9	0.5˚S
Grid_13	35.7˚E	1˚S	Grid_31	36	1˚S
Grid_14	35.7˚E	0.9˚S	Grid_32	36	0.9˚S
Grid_15	35.7˚E	0.8˚S	Grid_33	36	0.8˚S
Grid_16	35.7˚E	0.7˚S	Grid_34	36	0.7˚S
Grid_17	35.7˚E	0.6˚S	Grid_35	36	0.6˚S
Grid_18	35.7˚E	0.5˚S	Grid_36	36	0.5˚S

3.0 DATA AND METHODS

This study utilizes monthly evapotranspiration data from the Meteosat Second Generation's (MSG) Land Surface Analysis Satellite Applications Facility (LSA-SAF) obtained as 10-daily averages as well as monthly Normalized Difference Vegetation Index (NDVI) obtained from the Moderate Resolution Imaging Spectrometer (MODIS) as twice-monthly averages for the period September 2009 to November 2012. Pearson product moment correlation analysis is used to assess the relationship between the two data sets while a time series analysis is used to monitor the stability of the computed correlations. The correlation analysis is given as;

$$r_{xy} = \frac{\sum_{i=1}^{n}\{(x_i-\bar{x})(y_i-\bar{y})\}}{\sqrt{n\sum_{i=n}^{n}\{(x_i-\bar{x})^2(y_i-\bar{y})^2\}}} \quad \text{... (9)}$$

Root Mean Square error was also computed to find out the degree of error between the 2 datasets. It's given as

$$RMSE = \sqrt{\frac{\sum(X_{obs,i}-X_{mo\,del,i})^2}{n}} \quad \text{........(10)}$$

4. RESULTS AND DISCUSSION

4.1 Scatter plots and Pearson product moment correlation analysis

The study showed that for quite a number of grid locations, the computed pearson correlation was significant at 95% confidence level when tested using the student t statistic. However, the correlations though significant were not strong enough with less than 11% of the grid locations explaining more than 25% of the variance in the relationship between evapotranspiration and Normalized difference vegetation index. Figures 2 and 3 below show the scatter plots for selected grid locations while table 1 shows the computed correlations between the two data sets for the 36 grid locations analyzed.

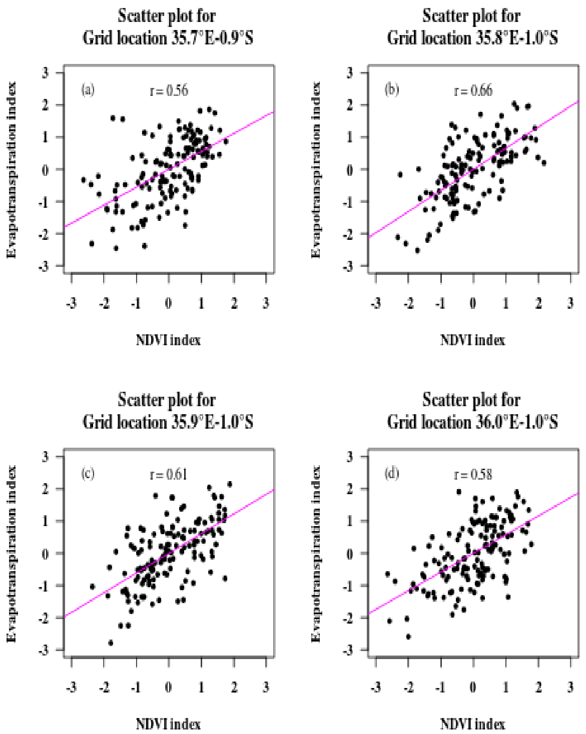

Figure 2: Scatter plots between Evapotranspiration and NDVI for various grid locations showing a positive trend with strong and significant correlation values. 80% of the grid locations showed significant positive trends

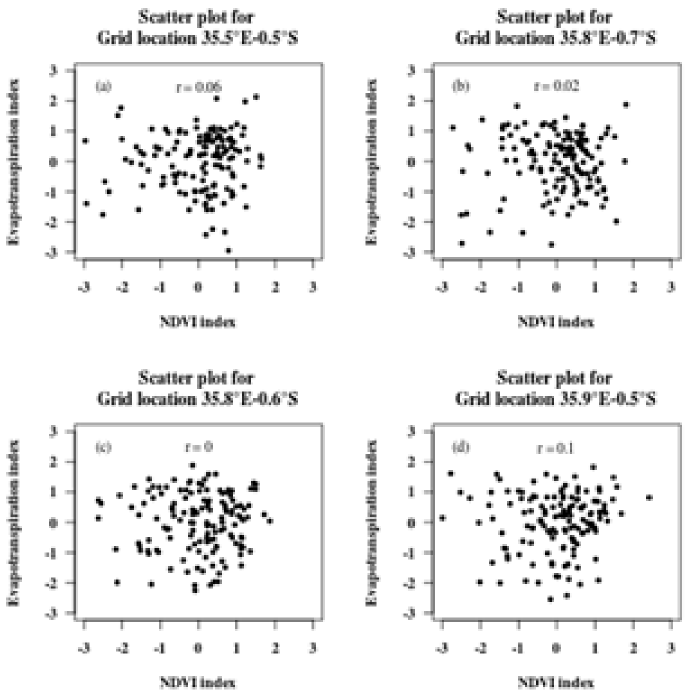

Figure 3: Scatter plots between Evapotranspiration and NDVI for grid locations 6, 22, 23, and 30 representing the few grid locations which showed relationships not significant at the 95% confidence level.

Table 1: Correlation coefficients between Evapotranspiration and NDVI. (Values above 0.162 are significant at the 95% confidence level.)

Grid location	Pearson Correlation	Grid Location	Pearson Correlation	Grid Location	Pearson Correlation	Grid Location	Pearson Correlation
1	0.48	10	-0.09	19	0.66	28	0.28
2	0.48	11	0.06	20	0.11	29	0.24
3	0.46	12	0.17	21	-0.04	30	0.06
4	-0.14	13	0.5	22	0.02	31	0.58
5	-0.03	14	0.56	23	0	32	0.32
6	0.06	15	0.35	24	0.17	33	0.23
7	0.54	16	0.09	25	0.61	34	0.25
8	0.41	17	0.15	26	0.12	35	0.49
9	0.35	18	0.29	27	0.16	36	0.46

4.2 Time series plots

Time series plots for NDVI and Evapotranspiration indices were made for the period January 2001 to October 2012. While in many grid locations the 2 indices tended to show a uniform direction, there were a few locations where the general direction of the anomalies was not in tandem. Grid locations like 19 and 25 showed uniformity in the general direction of the anomalies whereas locations like 23 and 22, the general movement was non-uniform. Figure 5 shows time series plots for both NDVI and evapotranspiration indices for 4 grid locations.

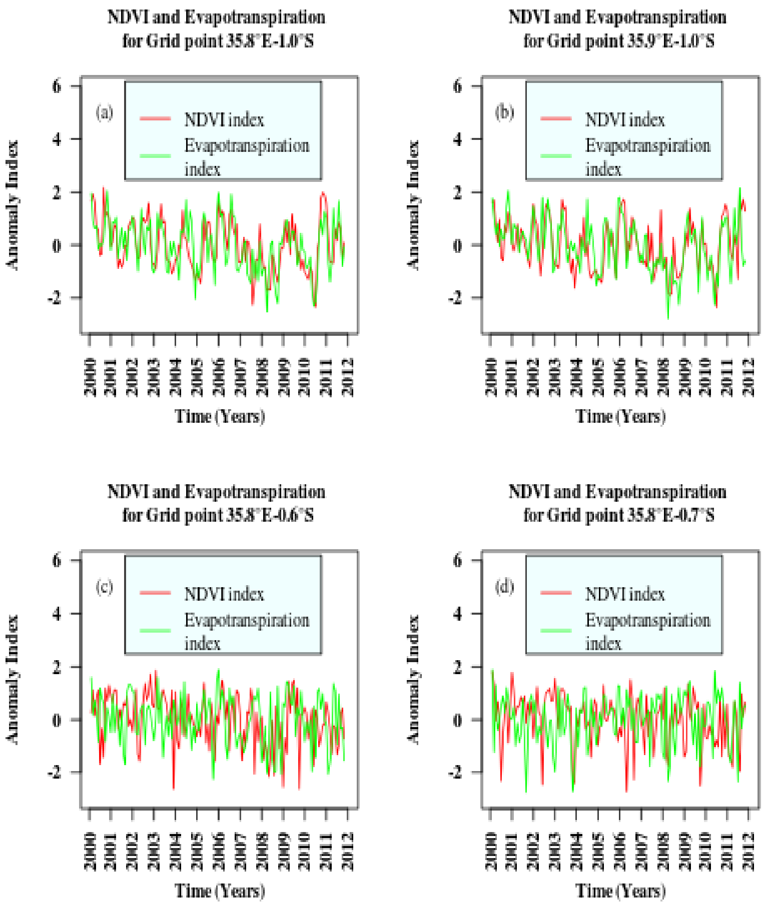

Figure 5: Evapotranspiration and NDVI indices for a) Grid location 19, b) Grid location 25, c) Grid location 23 and d) Grid location 22. Anomalies in most of the locations were in tandem.

4.3 Root Mean Square Error

RMSE was computed between NDVI and Evapotranspiration and the results tabulated as shown in table 2. The values indicate that RMSE was relatively large for most locations. Thus, one should be cautious while applying an interchange between the two datasets for various applications.

Table 2: Root Mean Square Error (RMSE) computed between NDVI and evapotranspiration for 36 grid locations within Narok County

Grid location	RMSE	Grid Location	RMSE	Grid Location	RMSE	Grid Location	RMSE
1	0.98	10	1.41	19	0.79	28	1.15
2	0.97	11	1.31	20	1.27	29	1.18
3	0.99	12	1.23	21	1.38	30	1.32
4	1.45	13	0.96	22	1.33	31	0.88
5	1.37	14	0.90	23	1.35	32	1.12
6	1.31	15	1.10	24	1.23	33	1.18
7	0.92	16	1.29	25	0.84	34	1.17
8	1.04	17	1.25	26	1.27	35	0.97
9	1.09	18	1.14	27	1.24	36	0.99

4.4 Conclusions

The study has shown that NDVI and Evapotranspiration are related. The scatter plots for most of the selected grid locations within Narok County showed a positive linear relationship with most locations recording strong and significant correlation coefficients.

Time series analysis has shown that, in most locations, there is a general uniformity in both datasets with few locations recording a randomized direction. In general, the 2 datasets seem to have a similar signal in almost all the locations considered and one dataset can be used in place of the other for various applications.

However, one is advised to exercise caution when interchanging between NDVI and Evapotranspiration for various applications since the RMSE is appreciable in most of the locations considered for the study. One of the possible causes of discrepancy might be attributed to the difference in spatial resolutions between the 2 datasets where the Evapotranspiration had a spatial resolution of 3km while the Normalized Difference Vegetation Index data extracted from MODIS had a finer resolution of 0.25km. The study can be expanded to cover larger spatial domains and longer time scales to ascertain or reject the findings of this study.

REFERENCES

1 Rosema, A, Marjolein W and Steven F., 2010: Meteosat based agrometeorological monitoring and crop yield foreacasting using the energy and water balance monitoring system, ISPRS Archives XXXVI-8/W48 Workshop Proceedings: remote sensing support to crop yield forecast and area estimates.

2 Muthama, N. J., A. O. Opere and C.B. Lukorito (2003). Utilization of Meteorological products in agriculture and water sectors in Central and Eastern Kenya. *J. Afric.Met.Soc. Vol. 6*. No. 1, pp 58-64,

3 Huete A, K Didan, T Miura, E.P Rodriguez, X Gao, L. Ferreira, 2002: Overview of the radimetric and biophysical perfomance of the MODIS vegetation Indices, Remote sensing of Environment, 83, 195-213.

4 Purevdorji, R Tateishi, T. Ishiyama and Honda Y, 2010: Relationships betweeen percent vegetation cover and vegetation indices, Int. Journal of Remote sensing, 19, 3519-3535.

5 Davenport M.L and Nicholson S.E, 1993: On the relation between rainfall and the Normalized Difference Vegetation Index for diverse vegetation types in East Africa, *Int. J. Remote sensing*, 14, No.12, 2369-2389

6 Waring R.H., N.C. Coops, Fan W., and Nightingale, J.M 2006: MODIS enhanced vegetation index predicts tree species richness across forested ecoregions in the continguous U.S.A, Remote sensing of the environment, 103, 218-226.

7 Sindiga, I. 1999: Tourism and African Development: Change and Challenge of Tourism in Kenya. African Studies Centre, Research Series, Ashgate