# Estimation of actual evapotranspiration at large watershed scale in Africa using NOAA-AVHRR surface temperature and NDVI.

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## ABSTRACT

To estimate actual evapotranspiration on regional scale, seven subcatchments were choosen on fleuve Niger catchment where we have selected stations for representative meteorological measurements. Precipitation values are spatially represented by using Thiessen polygons and Kriging methods and, based on water balance equation, we deduce the actual evapotranspiration term.
The goal (objective) of this study is to deduce from the water balance equation the evapotranspiration term, to correlate remote sensing indicators (surface temperature and NDVI) and evapotranspiration data and characterise factors that affect this correlation

**KEY-WORDS :** Evapotranspiration, Global scale, Spatialisation, NDVI, Surface temperature

## INTRODUCTION

Sahelian (200 mm <RR<600 mm) and Soudano-Sahelian (600 mm < RR < 1100 mm) regions are buffer zones between Saharian desert and Equatorial more humid regions. Within these two fragile entities, a lot of environmental problems occur : drought, food security, famin, desertification. In these regions evapotranspiration represents the main term of the Soil -Plant-Atmosphere Continuum. A better knowledge of this parameter is therefore essential especially in this part of the world where water is the main limiting factor for agriculture production. Teledetection technics to improve its estimation has already been researched by a lot of people who have tried to develop methodologies for approaching this complex phenomenon (Séguin B., 1994; Bhaskar J., 1986, W. P. Kustas et al., 1993; Bhaskar J. et al., 1994, John C. (1990), Sogaard H. (1988), Rosema A. (1990)). Latent heat fluxes will differ at each parcel in a given site due to a lot of factors such as soil characteristics, type of vegetation cover, topography, water availability, etc...
An other difficulty comes from the size of the study zone. But by its global approach, and with its possibilities to observe zones unaccessible to man, teledetection could contribute to the development of our knowledge of ETA estimation (actual evapotranspiration) that plays a major role in efficient water management and agricultural production.

## 1. OBJECTIVES

- Calculate the actual annual evapotranspiration (ETA) at global scale
- Study ETA variation and precise estimations methods according to agroclimatic conditions (North -South Transect) and rainfall level.
- Determine the interest of remote standard indicators given by NOAA-AVHRR by studying their correlation with actual annual evapotranspiration and evaluate the potentiality of remote data to improve agrometeorological models

## 2. STUDY SITES AND DATA

### 2.1 Selected study sites

Seven subcatchments of the big Niger catchment (1125000 km²) were choosen (Table 1). Subdivsions of the Niger Basin are those adopted by ORSTOM (Rodier, 1970 ; Brunet-Moret, 1986) No other zone was retained in the Delta Central and the Niger Inférieur as the choice was guided by the creation of a North - South transect from the border of the saharian desert to the humid forest in the Guinean zone.. The name of the subcatchments corresponds to the name of the city (or village) at the outlet of the subcatchment.

**Table 1** : Subcatchments selected for the study

| Subdivision | Subcatchment name | Streamflow | Outlet location | | | Area (km²) |
|---|---|---|---|---|---|---|
| | | | Latitude | Longitude | Altitude (m) | |
| Niger supérieur et Bani | Bougouni | Baoulé | 11° 25' N | 7° 30' O | 330 | 15 700 |
| | Douna | Bani | 13° 12' N | 5° 54' O | 287 | 102 000 |
| | Koulikoro | Niger | 12° 51' N | 7° 32' O | 290 | 120 000 |
| | Pankourou | Bagoé | 11° 27' N | 6° 34' O | 309 | 31 800 |
| Niger moyen | Alcongui | Gorouol | 14° 45' N | 0° 36' E | 264 | 44 850 |
| | Banikoara | Alibori | 11° 17' N | 2° 50' E | 219 | 8 170 |
| | Garbé-kourou | Sirba | 13° 45' N | 1° 37' E | 195 | 38 750 |

### 2.2 Used data

Main data are rainfall (RR), waterflow (Q) at the oulet of the different subcatchments and satellite images. Q and RR were found at the Hydroniger Institute (Niamey - Niger) and National Meteorological Bureaux for the period 1980-1990. Satellite data used to produce indicators were the raw AVHRR 4-km Global Area Coverage (GAC) data. They were preprocessed and provided by the MTV unit (Monitoring Tropical Vegetation) of the Joint Research Center of the European Community (JRC- EC - Ispra -Italy).

These images are monthly maximum composite value of surface temperature and NDVI. They provide an estimated value of maximum surface temperature and maximum NDVI for each month data (Bartholomé E., 1996; Eidenshink & Faundeen, 1994; Lambin &Ehrlish, 1995)

## 3. ETA ESTIMATION METHODOLOGY

To verify remote estimations of ETA, ground based annual ETA were calculated with a classical water balance approach :

$$Q = (RR - ETA)\,su + \Delta S \qquad (1)$$

with :

$Q$ = cumulated streamflow at the outlet of the catchment [$m^3$]
$RR$ = mean rainfall of the catchment per surface unit [m]
$ETA$ = Actual evapotranspiration per surface unit [m]
$\Delta S$ = water stock variation accumulated inside the catchment [m]
$su$ = water catchment size [$m^2$]

But as the present study has an annual time step and as the catchments have relatively low drainage capacities, the stock varaition can be neglected and equation (1) becomes :

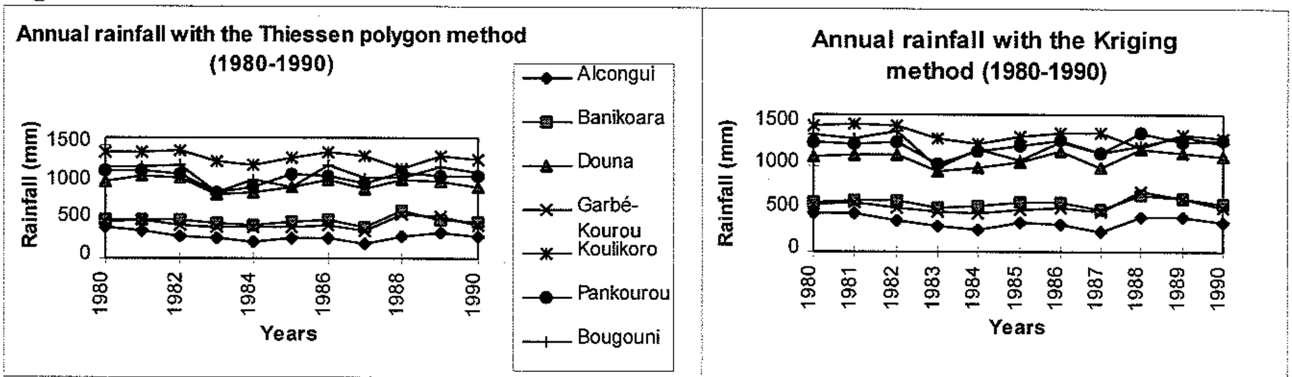
$$Q = (RR - ETA)\,su \qquad (2)$$

Punctual rainfall data were spatialised to estimate the all basins water input by applying the Thiessen Polygones (OMM, 1983) and the Kriging methods (Kerckler D., 1995). ETA is then extracted from equation (2).
Finally, for each subcatchments remote GAC data were extracted and analysed with IDRISI software to provide remote simple indicators of actual Evapotranspiration (Touré, 1996).

## 4. RESULTS AND ANALYSIS

### 4.1. Hydrological terms (rainfall and ETA)

***Figure 1 :*** Annual rainfall curves of the 7 subcatchments




**Analysis and discussions**
Curves of figure 1 describing climate from 1980 to 1990 in the soudano-sahelian and sahelian zones show clearly a drought period in 1984 and 1987 and the start of rainy years from 1988. Inter annual variation of rainfall is important (Table 2). It increases from South (6% in Koulikoro) to North (21% in Alcongui). A difference of about 10% can be observed between the two spatialisation methods to estimate rainfall. Coefficeint of variation are high, what could be expected in the sahelian and soudano-sahelian climate where rainfall occurs randomly. ETA values of the different subcatchment behave in time like rainfall. Coefficients of variation of Rainfall and ETA have the same order of magnitude. Evapotranspiration rate are quite similar to rainfall values. Several factors acting together could explain the high value of ETA compared to rainfall :

- influence of tropical anticyclone , vector of subsident air mass
- Saharian desert proximity, responsible for dry wind (Harmattan)
- evaporating power of air extremely high in these regions, several times higher than available water.

Mean values of ETA are systematically underestimated (overestimated) by about 10% with the Thiessen Polygon method (Kriging Method) due to 2 possible reasons :

- an heterogeneity in the density of rainfall stations : the highest density is always situated where the rainfall is the highest, what is not conform with the hypothesis of Thiessen method and can lead to error of estimation.
-the kriging method uses a gridded approach that slightly overestimate the size of the catchment, i.e. each grid of the catchment even if not completely included in the catchment is taken into account for the calculation of the catchment size.

***Table 2*** : Hydrological terms (from South to North)

| Subcatchment | Mean annual rainfall (mm) | | Rainfall Coefficient of variation (%) | | Mean annual ETA (% Rainfall) | | ETA Coefficient of variation (%) | |
|---|---|---|---|---|---|---|---|---|
| | Kriging | Polygon | Kriging | Polygon | Kriging | Polygon | Kriging | Polygon |
| Pankourou | 1241 | 1073 | 8 | 9 | 93,4 | 92,4 | 6 | 6 |
| Bougouni | 1285 | 1158 | 10 | 11 | 92,5 | 91,7 | 10 | 10 |
| Banikoara | 1095 | 962 | 8 | 10 | 97,6 | 96,3 | 9 | 10 |
| Koulikoro | 1364 | 1340 | 6 | 6 | 85,0 | 84,7 | 6 | 6 |
| Douna | 1086 | 982 | 8 | 9 | 95,4 | 94,9 | 7 | 7 |
| Garbé-k | 534 | 462 | 13 | 14 | 95,3 | 94,6 | 13 | 14 |
| Alcongui | 351 | 294 | 20 | 21 | 97,2 | 96,6 | 22 | 23 |

## 4.2. Satellite Data

One of the objectives of this work is to compare, qualitatively, satellite indicators (NDVI and Surface temperatures) to actual ground measured evapotranspiration in order to evaluate the quantity of information that should provide this remote approach. Annual surface temperatures (max and mean) and annual NDVI values are obtained from monthly data calculated by using the 'maximum composite value' method.

***Table 3*** : Subcatchment determination coefficient ($R^2$) of the ETA- remote indicators relationships (except Banikorara where data were lacking).

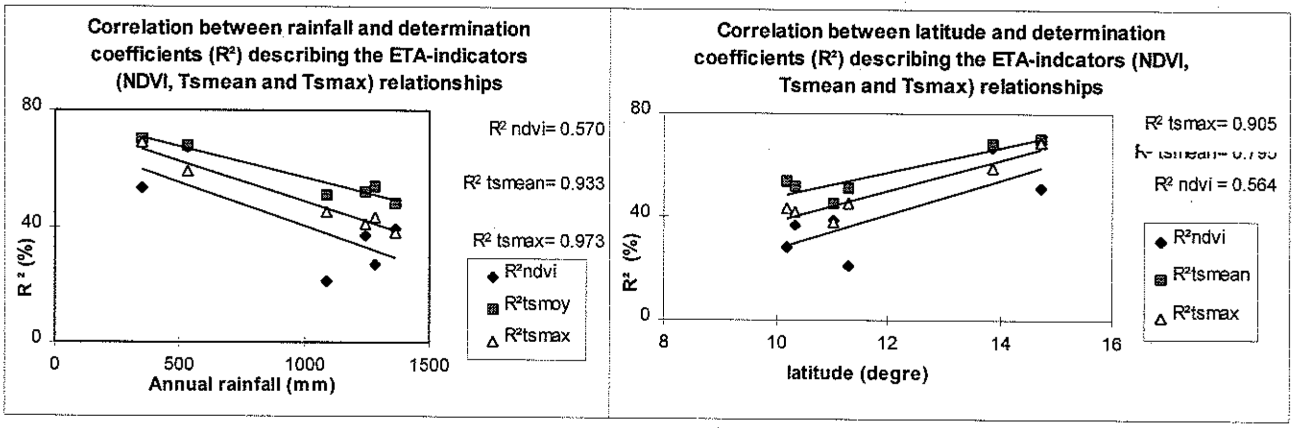
| Sub-Catchments | Determination coefficient ($R^2$) % | | | Annual mean rainfall (mm) | Latitude (Degre) |
|---|---|---|---|---|---|
| | ETR-Tsmean | ETR-NDVI | ETR-Tsmax | | |
| Pankourou | 52 | 37 | 41 | 1159 | 10° 19' |
| Bougouni | 54 | 27 | 43 | 1189 | 10° 25' |
| Koulikoro | 48 | 39 | 38 | 1359 | 10° 46' |
| Douna | 51 | 21 | 45 | 1036 | 11° 11' |
| Garbé-Kourou | 68 | 67 | 59 | 509 | 13° 45' |
| Alcongui | 70 | 53 | 69 | 341 | 14° 45' |

**Analysis and discussions :**

The best indicator is the annual mean of the monthly maximum surface temperature (Tsmoy)
ETA seems quite weakly related to NDVI.
The correlation between Temperature and ETA increases moving northward but it depends more on rainfall and its associated clouds cover that are responsible for the disruption of the ETA-Indicators relationships. High $R^2$ values in the North of the sutdy zone might also come from the homogeneity

of vegetation that will reduce bidirectionnal effects. The evolution of $R^2$ with rainfall values and latitude is described in Figure 2

***Figure 2*** : Correlation between Rainfall, latitude and $R^2$ of the relationships between ETA and remote indicators




Rainfall rate is highly correlated to the coefficient of determination of the Max Surface Temperature - ETA relationship. It is much less correlated to the $R^2$ of the NDVI-ETA relationship. Differences between NDVI and Surface Temperatures (Max and Mean) results might be due to the weak correlation with ETA and/or to the bad data quality.

The quality of the relationship (given by the $R^2$ value) seems more related to rainfall than to latitude.

## CONCLUSIONS

The results of the 2 methods of rainfall estimation differ at about 10 %.

Kriging method seems better for this zone of the world where the density of stations is varying but the procedure to estimate the size of the catchment with this approach must be improved.

Evapotranspiration rate expressed in percentage of annual rainfall are very high (84 to 97%). It's increasing from South to North. It is linked to the semi-arid and arid character of the zone of study.

Link between remote indicators and ETA estimation is strongly influenced by clouds cover occurrence.

Vegetation heterogeneity in the study zone seems to act to satellite data quality (bidirectionlal effect)

The relationship between satellite indicators (Tsmax, Tsmean and NDVI) and Actual evapotranspiration is relatively weak. Tsmean indicator gives the best results. The relationship seems to improve from South to North and from high rainfall to low rainfall values; the best linearity in the relationship is observed for rainfall. Following this principle, potentialities of this type of remote indicator for estimating actual evapotranspiration would reduce with increasing annual rainfall and moving southward. Consequently, the approach shows clearly the limits of teledetection in the soudano-sahelian zone. It could, in association with agrometeorological models, provide informations or controls able to improve global quality of the monitoring of vegetation state in the sahelian zone.

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