Estimation and cartography of the evapotranspiration from the data AATSR in Sudano–sahelian environment: case study of Kolondièba-Tiendaga basin (Mali)

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Abstract

Information on the space and temporal variation of the evapotranspiration on a basin area is of capital importance in many environmental disciplines, such as hydrology, agriculture, integrated management of the water resources, meteorology, etc. Moreover, this information plays a crucial part in the processes of interaction between the hydrosphere-Biosphere-Atmosphere, and water cycle. The evapotranspiration can be measured through two approaches (conventional or traditional and remote sensing approaches). The conventional approaches make it possible to have very precise results but confined on reduced spaces. While the approaches of remote sensing lead to such satisfactory results likely to be extended to broader zones.

The satellite images are more and more used to estimate and map the space and temporal distribution of the evapotranspiration starting from patterns such as SEBS (Surface Energy Balance System). This article has the results of the estimate of the evapotranspiration starting from model SEBS (Surface Energy Balance System) on the basin area of Kolondièba-Tiendaga (3050 km^2) in sudan-sahelian climate, in Southern Mali. The results of this study show a strong correlation between the evapotranspiration and the evaporative fraction from 2003 up to 2008, where the coefficients of correlation vary between 0.60 and 0.90. On the other hand, this coefficient becomes lower than 0.50 for the two last years 2009 and 2010 (0.34 and 0.40). The values of the evapotranspiration vary between 1 and 3mm/J $^{-1}$

Keywords: Evapotranspiration, SEBS, evaporative fraction, Basin of Kolondièba-Tiendaga, AATSR images

I Introduction

The estimation by remote sensing of the corresponding evapotranspiration (to the latent flux of heat) is based on the evaluation of the energy balance of surface through several properties of surface, such as the albedo of surface, the temperature of surface, the vegetation index (LAI, FCover, NDVI) and meteorological data[7]. The measure continues and the spatial variation of the evapotranspiration, at various scales (ladders) are important parameters in the evaluation of agriculture water requirement [24]. This evapotranspiration represents a key parameter in several environmental disciplines, such as, hydrology, agriculture (farming), integrated management (joined) by water resources, [24], [25] and play a dominating role in the process of interaction between hydrosphere-Biosphere-Atmosphere and water cycle. It depends on the availability of water, and the incidental solar radiation and reflects essentially the interaction between water resources and climate. The reliable estimation of the evapotranspiration allows improve the performance of the systems of irrigation.[24], [25], and can be made through two approaches (the conventional or classical approaches and the surrounding areas of remote sensing).

The conventional approaches supply precise measures through homogeneous zones, on small scales, and cannot be spread to hypermarkets, because of the regional variation of the climatic parameters, the heterogeneousness of the landscape and the dynamic nature of heat transfer processes. [33].

Among these conventional methods, the method of Penman-Monteih is both mostly known and used. This classical method combines (at the same time) energy and the balance sheet of mass transfer to model the evapotranspiration. It was proposed by Monteih in 1965 which leaned on the equation of Penman in 1948 [6].

Surrounding areas of remote sensing are based on the evaluation of the energy balance of surface through several properties of surface, such as the albedo of surface, the temperature of surface, the vegetation index (LAI, FC over, NDVI) and meteorological data[7], Among these surrounding areas of remote sensing , we can note the method SEBAL (Surface Energy Balance for Land) developed by[2,3,13,14,26], the method S-SEBI (Simplified Surface Energy Balance Index) finalized by, the method SEBS (Surface Energy Balance Système, developed by[15,19,18,26,27,28] the method TSEB (Two-Source Energy Balance) [8,16,21]

[25] proposed a method simplified by the model S-SEBI, based on the concept of the evaporative fraction. This model permits to consider the evapotranspiration from the contrast between the dry and wet areas given by [24], also proposed a method based on the concept of the "eporative fraction", with a factor of correction of 0.034 on the pond the Indus in Pakistan to estimate the daily evapotranspiration.

In the Malian context, the estimation of the evapotranspiration was always made from the conventional methods [32]. Because of the limits observed in the use of the conventional methods, this work is based on the preceding sensing theories. Our survey sets up as objective the estimation and the mapping of evapotranspiration from the satellite pictures AATSR (ENVISAT) developed by ESA (European Spatial Agency) over a period of 8 years, between 2003 and 2010.

II. Materials and Methods

2.1 Frame of study:

The study concerns the basin of Kolondièba-Tiendaga located in southern Mali between the Longitudes and Latitudes 34 °W and 6. 82°W and 10.15°N and 11,08°N. This versant of a 3050 km ², is one sub pond of the cross-border pond of Bani (Fig.1). It is located on the upper pond of Niger, in approximately 262 km from Bamako (capital of Mali), and is limited to the North by the city of Kolondièba, to the South by the municipality of Sibirila until the border of it Quoted by Ivory, in the East by the municipality of Fakola and Bougoula, on the West by the municipality of Garalo (circle of Bougouni). Its release is to Tiendaga on the road of Fakola. Its physical characteristics are given in the figure 1.

The basin of Kolondièba-Tiendaga has a tropical transition climate or a South Sudan climate, characterized by the alternation of a warm and dry season (in November-April) and of a rainy season (May-October) when the rainfall average oscillates between 900 and 1200mm / year. The monthly average temperatures vary between 38 ° in May and 23 ° in December. The values of the relative humidity oscillate between 82 % in August and 38 % in February. The radiation is strong all year long, when the values of the potential evapotranspiration remain important, with a climax in May (161) (DNH-Mali, 1990). The geologic substratum is made of metamorphic and granitic rocks covered with washed tropical ferruginous, ferralitic and hydromorphous grounds. The relief is dominated by upstream trays to the pond, plains in the center and downstream slums the height of which can vary between 315 and 390 m. The vegetation is characterized by trees, shrubs, meadow, mixed up with annual agricultures.

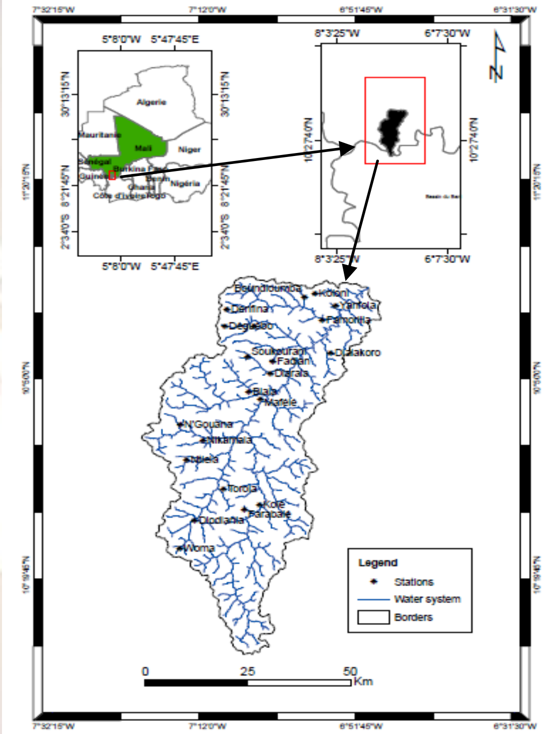


Figure1: map of the versant pond of Kolondièba-Tiendaga

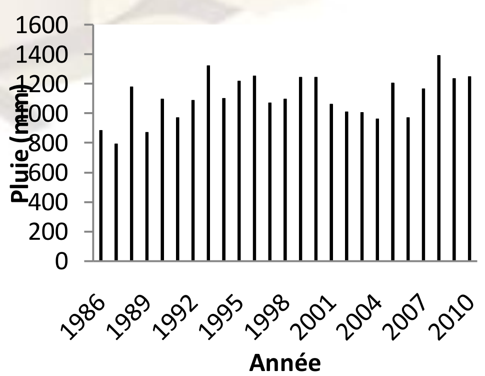


Figure 2: annual rainfalls recorded on the versant basin of Kolondièba-Tiendaga between 1986 and 2010

Table 1: morphometric characteristics of the versant pond

Designation	Value
Outlet	Longitudes : 11.066761 Latitudes : 6.846652
Altitude of outlet	313 m
Bassin surface	3050 Km^2
Main canal's lenght	158.30
Hydromorphic Network total lenght	5854.26
Strahler Order	7
Drainage density	1.895 km/Km^2
Perimeter	430 Km
Compactness Index	2.050 KG
Equivalent rectangle lenght	186 m
Equivalent rectangle width	16 m

Spectral band (µm)	Central wave lenght (µm)	Band largeness (µm)	Spatial resolution (Km)	Application
0.0545-0.565	0.555	0.02	1	Chlorophylla
0.549-0.669	0.659	0.02	1	Vegetation indication
0.855-0.875	0.865	0.02	1	Vegetation indication
1,580-1.640	1.61	0.03	1	Clean of cloud
3.50-3.89	3.70	0.30	1	surface sea temperature
10.40-11.30	10.85	1.00	1	Surface sea temperature
11.50-12.50	12.00	1.00	1	Surface sea temperature

2.2 Material

The satellite data used are acquired by in this study are the AATSR (Advanced Along Track Scanning Radiometer) ones and MERIS (Medium Spectrometer Imaging Radiometer) sensors on board ENVISAT platform of ESA launched 01 March 2002 on polar orbit. The sensor AATSR is intended to supply data on the atmosphere, the ocean, the earth (ground), and the ice (mirror, ice cream). The sensor MERIS is a spectrometer imager with average resolution (300m, recording) in 15 spectral ranges in the visible and the infrared close relation. It is especially used for the determination of vegetation index (NDVI, LAI) entering the model SEBS.

The data produced by ENVISAT will be used within the framework of the scientific research on the earth and the monitoring of the environmental and climatic changes. Besides, they will facilitate the development of operational and commercial applications. The sensor AATSR is one radiometer with sweeping with a spatial resolution of 1Km x 1Km, recording 7 spectral ranges in the visible and the infrared. The track of the sensor AATSR is chosen so as to insure continuity with the sets of data of ATSR1 and ATSR2 of the series of ERS1 and ERS2 of ESA. The characteristics of the sensor are given in table 2. Product ATS-TOA level 1P of AATSR is used in this work. They were acquired with the European Space agency (E.S.A) in the framework of the TIGER Initiative on Assessment of Water Resources in Africa under Global Climate Variability. These data were downloaded from the site http: // ats-merci-uk.eo.esa.int:8080 , and concern about more than 100 images in the period 2003 to 2010.

Besides the satellite data, are used meteorological data (temperature, the wind speed, the relative humidity) collected on ground station by the National Meteorological Direction of Mali.The solar radiation data used in this work are collected in [34]

Table 2: characteristics of the sensor AATSR of the satellite ENVISAT (Esa, 2009)

As for the geometrical resolution, the sensor AATSR acquires data according to two systems of curved sweepings: a Sweeping curved forwards and a Sweeping curved towards Nadir.

2.3 Methods

The methodological approach used in this study is based on the SEBS (Surface Energy Balance System) model developed by ESA[15,19,18,27,28]. It is settled in the software BEAM (BASIC ERS, ENVISAT and ASAR, MERIS Toolbox) as modulate. The BEAM software intended for georeferencing, assessment , analysis and visualizing of satellite images, in particular those produced by ESA (MERIS, AATSR, ASAR, etc.). The image AASTR was corrected atmospherically by the SMAC (Simplified Method for Atmospheric Corrections) model used also as a module of BEAM before being used in the SEBS model. The practical application of SMAC is to change the radioactive transfer equation to calculate the surface reflectance.

This model SEBS is constituted of a set of tools for the determination of the physical properties of ground surface, such as emissivity, albedo, temperature and plant location setting.

Based on the contrast between the dry and wet areas, the SEBS pattern was introduced by [18] who proposed a method to calculate the evapotranspiration from the evaporative fraction. This concept of evaporative fraction base on ground surface energy balance to estimate the evapotranspiration was improved by [28]).

2.3.1 Estimation of the components of the energy balance The remote sensing and meteorological data are used to calculate the surface heat flux. The net radiation is divided into latent heat flux, sensitive heat flux and heat flux of the soil. The latent heat flux is calculated as a residue of the energy balance according to the following equation.

$$LE = R_n - G - H$$

Where R_n is the net radiation resulting respectively from the balance of incoming and outgoing radiation (W/m2): latent heat flux (W/m2)
G: Soil heat (W/m2) H: Sensitive heat (W/m2)
R_n and G can be estimated locally [1] by using meteorological data (and regionally by incorporation of emitted and thoughtful radiation distributed spatially [12] (

2.3.2 Net radiation (Rn): the ground surface radiation balance is given by the following formula

$$R_n = R_{s\downarrow} - R_{s\uparrow} + R_{L\downarrow} - R_{L\uparrow}$$

Where:

R_n net radiation

$R_{s\downarrow}$ short wavelength radiation (0.14-4µm) resulting from the sun

$R_{s\uparrow}$ shortwave radiation reflected by earth's surface

$R_{L\downarrow}$ longwave atmospheric radiation

$R_{L\uparrow}$ longwave radiation (> 4µm) emmitted by earth's surface

$R_{s\downarrow}$ [22] is calculated from the product of immediate radiation arriving on the soil. The solar radiation absorbed by the surface of the soil is calculated according to the following relation:

$$R_{abs} = (1-\alpha)R_{s\downarrow}$$

Where,

α is the albedo of surface. It is determined from measure of narrow tapes by the technique of weight average proposed by [24]. The radiation arriving of big length is estimated on the basis of the measures the soil and air temperature and the pressure of vapor by using the following relation:

$$R_{L\downarrow} = \varepsilon_a \sigma R_a^4$$

Where,

ε_a is the emissivity of the atmosphere $\left[\varepsilon_a = 1{,}24\left(\frac{e_d}{T_a}\right)^{1/7}\right]$,

The constant of Stefan-Boltzman is (5.67x10-8W / m-2K-4, Your is the air temperature (K) and ed is the deficit of pressure to mbar). The radiation of big length of wave going out () is obtained from the temperature of surface by ignoring the small contribution of the radiation of the sky reflected by using the following equation:

$$R_{L\uparrow} = \varepsilon_s \sigma T_s^4$$

Where is the emissivity of surface and is the temperature of surface ° (K). According to [30], the emissivity (is) for the range of 8-14µm can be predicted from the NDVI (normalized indication of vegetation) with a strong correlation. The emissivity is thus calculated from the NDVI by using the following logarithmic relation:

$$\varepsilon_s = 1.0094 + 0.047 x \ln(NDVI)$$

The quantity of net radiation received by the surface is the sum of all the entering and taking out radiations and is calculated according to the equation below

$$R_n = (1-\alpha)R_{s\downarrow} + \varepsilon_a \sigma T_a^4 - \varepsilon_s T_s^4$$

2.3.3 Flow of heat of the soil (G)

The flow of heat of the ground (G) is collectively considered as a fraction of the net radiation R_n dependent on the indication of the surface foliar (LAI) and of the NDVI Normalized Difference Vegetation Index [10]. He can be upper in 0.3 Rn for the lower and naked grounds in 0,1Rn for zones covered with vegetation [12]. Several studies showed that the ratio G/Rn of the day is concerning the other factors, such as the quantity of vegetation presents [17, 9, 2, 3] presented the following logarithmic relation. The flow of heat of the soil G.

$$G = R_n\left(\frac{T_s}{\alpha}\right) x \left(0.0038\alpha + 0.0074\alpha^2\right) x \left(1 - 0.98\, NDVI^4\right)$$

2.3.4 Sensitive flux heat (H)

The estimation of the reliable values of flow of sensitive heat is the most difficult aspect of this methodology because it depends on the aerodynamic resistance. Hour is collectively expressed as a function of Ts and Ta

$H = \rho c_p (T_s - T_a)/r_a$ Where ρ is the density of the dry air (Kgm-3), Cp is the capacity of specific heat of the air (Jkg-1C-1), and Ra is the aerodynamic resistance of the transport of heat (m-1). Ra is estimated by the theory of similarity of Monin-Obukhov Businger, 1988 [13]. Numerous semi-empirical models were proposed to estimate Ra and H, [29, 31,5]. Among these models, model presented by [4], proposes the simplest to consider H from some points of measure easily obtained, such as the NDVI, Ts and Your. The main problem of this method is the overestimation of H in urban zones where the indication of vegetation is weak where from an overestimation of HIM (IT) [23].

To avoid this problem a model of semi-empirical aerodynamic resistance was proposed by [29]

$$r_a = 4{,}72\left\{\ln\left(z/z_0\right)\right\}^2/\left(1+0{,}54u\right)$$

Where z is the height of the wind speed (m), z_0 is the length of roughness of surface (m) and u is the wind speed (ms-1).

[11, 20] showed that z_0 can be estimated from indication of vegetation, such as the NDVI and the ratio of NIR/R. [9] also connected (bound) z_0 (cm) with the NDVI to estimate(esteem) the flows of surface at the regional level.[20] used an exponential relation to consider z0 from the ratio NIR / R

$$z_0 = \exp\left(0.01021 + 0.1484\left(NIR/\mathrm{Re}\,d\right)\right)$$

2.4 Estimation of the daily evapotranspiration

The method of estimation of the evapotranspiration used here is based on the concept of the evaporative fraction. This evaporative fraction is the relationship of the latent flux of heat on the sum of the latent and sensitive flows of heat (LE/LE+H). Besides, the product of the evaporative fraction and the daily net radiation can supply and of the daily evapotranspiration on the pond the Indus in Pakistan. Several studies proved that this technique is reasonable with differences of daily evapotranspiration at least of 1mm J^{-1} [17]. So, the current evapotranspiration is estimated according to the following formula:

$$ET = 0.034xEFxR_{n,d}$$

Where EF is the evaporative fraction (W / m-2), Rn, d is the daily net radiation (W/m-2), and 0.0345 is a factor of correction proposed by [24]. The evaporative fraction and the daily net radiation were calculated from the model SEBS (Surface Energy Balance System).

The 21 pluviometric stations are stacked on the map obtained from the model SEBS with the aim of the extraction of the values of pixels. These values of 21 stations are used in ArcGIS 9.3 to make the interpolation of the data of the evapotranspiration.

III. Results and Discussions

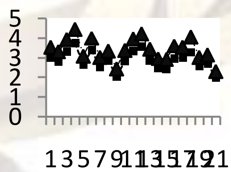
All in all, we worked on more than 100 satellite images AATSR of the flat train ENVISAT of the European Space agency (ESA) to estimate and map the potential evapotranspiration. The model SEBS (Surface Energy Balance System) developed by [15, 18,19,27,28] allowed to obtain these results. 21 pluviometric stations spatially distributed on the pouring pond were of use to the extraction of pixels (1Kmx1Km to make the various elaborated calculations and the maps relative to this work of cartography of the evapotranspiration in sudano-Sahelian environment, south Mali. All the values of the current evapotranspiration for the period of our study (2003- 2010) vary between 1 and 3 mm J-1 picture3). This study shows a very good correlation between the values of the current evapotranspiration and those of the evaporative fraction for 2003s until 2008, when the coefficients of correlation vary 0.60 (coefficient of correlation of 2005) in 0.90 (coefficient of correlation of 2008) (figure3). As regard to the values of the last two years, the values of the coefficients of correlation vary between 0.34 and 0.40, respectively for 2009 and 2010.

Several studies have proved that this evapotranspiration estimation technique is satisfactory with differences in daily evapotranspiration of less than 1mm J^{-1} [17].

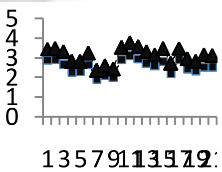
Table 3: values of evapotranspiration measured from AATSR's data from 2003 to 2010

Stations	2003	2004	2005	2006	2007	2008	2009	2010	Moy	Min	Max	Ecart
1	3,03	2,88	3,69	2,68	2,66	2,86	3,36	3,26	**3,05**	**2,66**	**3,69**	**0,36**
2	2,80	2,90	3,48	3,09	2,75	2,82	3,15	3,26	**3,03**	**2,75**	**3,48**	**0,26**
3	3,32	2,67	3,37	3,23	2,62	2,97	3,06	3,43	**3,08**	**2,62**	**3,43**	**0,31**
4	3,73	2,28	3,41	3,08	2,14	2,84	3,13	2,84	**2,93**	**2,14**	**3,73**	**0,54**
5	2,64	2,30	3,43	2,66	2,28	2,98	2,98	3,27	**2,82**	**2,28**	**3,43**	**0,42**
6	3,38	2,65	3,05	2,46	2,50	3,03	3,28	3,72	**3,01**	**2,46**	**3,72**	**0,45**
7	2,53	1,92	2,94	2,55	2,73	3,10	2,49	3,28	**2,69**	**1,92**	**3,28**	**0,43**
8	2,84	2,11	2,66	2,82	2,77	2,61	3,28	2,77	**2,73**	**2,11**	**3,28**	**0,32**
9	2,03	1,99	3,12	2,32	2,47	2,43	2,79	2,86	**2,50**	**1,99**	**3,12**	**0,40**
10	2,83	2,90	3,19	2,21	2,30	2,75	2,89	3,26	**2,79**	**2,21**	**3,26**	**0,37**
11	3,34	3,12	3,15	2,31	2,39	2,43	3,17	3,17	**2,88**	**2,31**	**3,34**	**0,43**
12	3,57	2,94	3,37	2,49	1,66	2,38	3,07	3,22	**2,84**	**1,66**	**3,57**	**0,63**
13	2,86	2,73	3,06	2,32	1,31	2,14	3,36	3,27	**2,63**	**1,31**	**3,36**	**0,68**
14	2,47	2,60	3,22	2,89	2,50	2,08	3,08	3,52	**2,79**	**2,08**	**3,52**	**0,47**
15	2,44	2,82	3,40	2,28	1,26	2,29	2,59	3,04	**2,51**	**1,26**	**3,40**	**0,64**
16	2,97	2,21	3,12	2,39	1,79	2,78	3,07	2,94	**2,66**	**1,79**	**3,12**	**0,48**
17	3,01	2,92	3,21	2,25	2,74	2,11	2,65	2,90	**2,72**	**2,11**	**3,21**	**0,38**
18	3,26	2,42	3,76	2,43	1,91	2,20	2,79	3,04	**2,73**	**1,91**	**3,76**	**0,61**
19	2,56	2,32	3,17	2,64	2,07	1,83	2,74	2,98	**2,54**	**1,83**	**3,17**	**0,45**
20	2,69	2,52	2,88	2,23	1,51	1,77	2,53	2,66	**2,35**	**1,51**	**2,88**	**0,48**
21	1,99	2,53	2,74	2,61	2,45	2,40	2,74	2,54	**2,50**	**1,99**	**2,74**	**0,24**

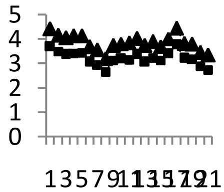
2003



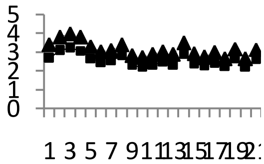
2004



2005



2006



2007

2008

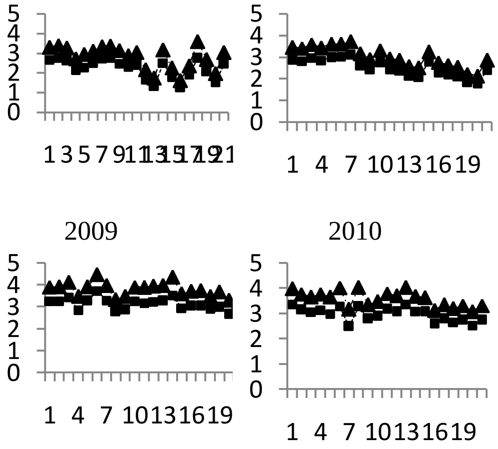


Figure 3: curves tendency of evaporation-evapotranspiration from 2003 to 2010

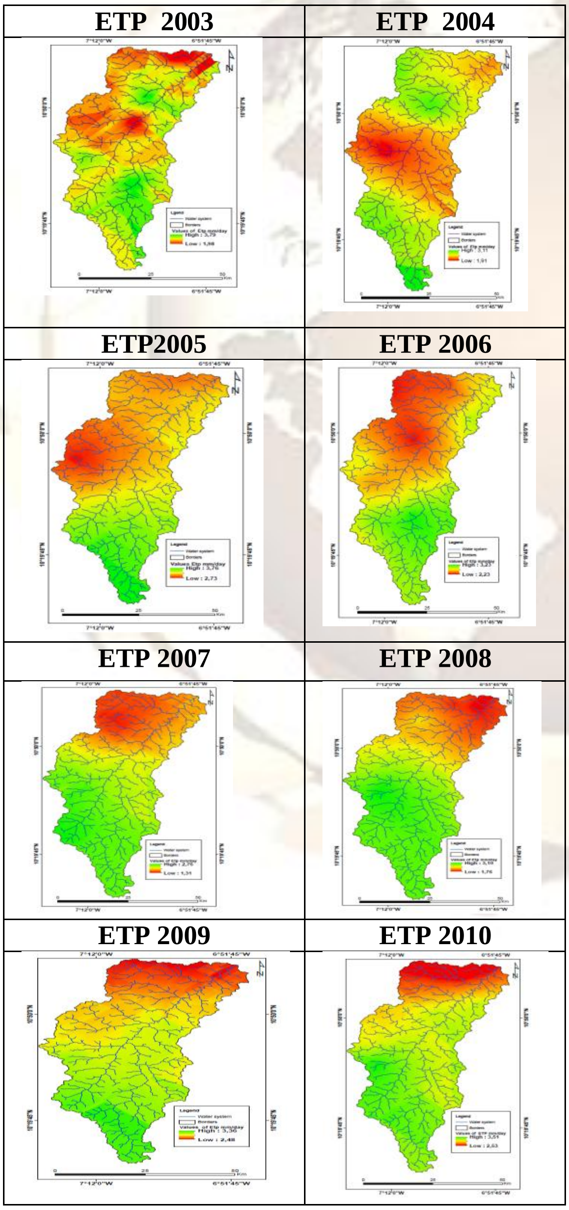


Figure 4: Evapotranspiration maps of Kolondièba-Tiendaga basin from AATSR images over the period 2003- 2010.

IV Conclusion

To day, the use of the conventional approaches in the measurement of the biophysical parameters, particularly evapotranspiration appear more and more limited with to the heterogeneity of the landscapes and it dimensions.

The methods of remote sensing appear to this effect as complementary (additional) means in these conventional or classic approaches where from their very big use on an international scale.

SEBS model use in in this study, gives a satisfactory results. Indeed, the values of the evapotranspiration found vary between 1 and 3 mm / J^{-1}. It was observed a strong correlation between the evaporative fraction and the evapotranspiration is R^2 upper in 0.60) for 2003s in 2008. While this coefficient is (R^2 lower than 0.50) for 2009s and 2010 (respectively, 0.34 and 0.04).

In the context of sustainable management of water resources, it is necessary to compare these results to those collected on ground.

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