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RESEARCH ARTICLE

MINIMAL VALUE OF THE HYDROUS DEFICIT INDEX ESTIMATE ON THE EARTH-ATMOSPHERE SYSTEM IN SOUTHERN PART OF CHAD

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ABSTRACT

This paper proposes a method to estimate an index of the deficit of water in the system Earth-Atmosphere in the southern region of Chad under the condition of insufficient, even total absence of data traditionally used, i.e. the temperatures of the earth surface and air. This method is based only on the exploitation of the maximum and minimum temperatures of the air since these are the two parameters traditionally registered in almost all the meteorological stations of Chad. The maximum temperature of the air was assimilated to the temperature of the Earth surface. This enables us to compute the estimated minimal annual and monthly values of this index, the maximum values of the relative error generated by this assumption and at last we proceed to the modelling of the time variation of the annual composite of that index over the whole region. The analysis of these numerical characteristics shows that the obtained results are acceptable and lead us to the general conclusion that this method is to be improved for the operational work in the considered area and this improvement can be done as needed data will be progressively available.

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INTRODUCTION

The global climatic reheating of the last years, exposed humanity to a multitude of problems. Among other problems which Man has to solve urgently is that of the water management on which depend his entire socio–economic development, (HAMADI *et al.*, 2003; The Man *et al.*, 1985; MADEC, 1963; TELIBI2004). Some methods relating to water management were proposed. The method usually met is related to the establishment of the hydrous balance equation. One of the mathematical forms of this equation can be represented by the following expression (XU, 2005):

$$P = Q + ETP + \Delta R, \qquad (1-1)$$

Where P represents precipitations, in mm, Q is the flux of run out water blade, ETP is the evapotranspiration, in mm and ΔR is the variation of the hydrous reserve, in mm. One notices that the seepage waters in the ground are contained in the last term. In the expression (1–1) component ETP is the most difficult to measure. Indeed, it is made up of the surface evaporation (which in this case is terrestrial surface) and the acting transpiration of the plants which cover this surface. It is practically impossible to dissociate one phenomenon from the other; from where the complexity in the determination of this component. As the two parts must always be measured together, this justifies the name given to this phenomenon: *evapotranspiration.* There is a measurement apparatus of the evapotranspiration usually known as the *container of evaporation*. However its installation as well as its exploitation requires constraining conditions. This explains that this instrument is rarely used. Furthermore, its high cost constitutes a limiting factor for most of developing countries. However, this phenomenon plays a significant role in most of the daily activities, particularly in agriculture (BRUTSSART, 1982). Several semi-empirical methods were set up to calculate the evapotranspiration in certain mediums, (BOUCHET, 1963; BOUTELJAOUI *et al.*, 2012; COURAULT *et al.*, 2005; FARID, 2007; IGBADUM, 2006). The formulas obtained, result from the data processing of meteorological observations relating to the following parameters: temperature of acting surface, temperature of the air, relative moisture of the air, speed of wind, sun radiation and other actinometrical data. These formulas are elaborated by taking into account specificities of the data sources of the localities of study; thus some readjustments of the empirical parameters are carried out to obtain the various constants which they contain. This

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explains the fact that the same data lead to different results according to the formula used, (BOUTELJAOUI *et al*., 2012; COURAULT *et al*., 2005; FARID, 2007; XU 2006). These formulas are divided into two great classes according to methodology used, namely the method of radiation and that of mass transfer. Concerning the formulas based on the method of radiation, one meets among other, the following ones, (Benoit, 2003).

- The formula of MAKKING worked out in 1957:

$$E = 0.77 \frac{\Delta}{\Delta + \gamma} \frac{R_g}{\lambda} + 0.2. \qquad (1.2)$$

- The Turk formula worked out in 1961:

$$E = \begin{cases} 0.015 \frac{T}{T+15} \left(R_g + 50\right), \ si\ f > 50\%, & (a) \\ 0.015 \frac{T}{T+15} \left(R_g + 50\right)\left(1 + \frac{50-f}{70}\right), \ si\ f \leq 50\%. & (b) \end{cases}$$

(1.3)

- The formula of Priestley worked out in 1972:

$$E = 1.26 \frac{\Delta}{\Delta + \gamma} \frac{R_n}{2.50}. \qquad (1.4)$$

- The formula of L INACRE worked out in 1993:

$$E = (0.015 + 0.00421 + 10 \quad 6z)(0.8R_s \quad 40 + 2.5Fu(T_m \quad T_d)) \quad (1.5)$$

- The formula of ABTEW worked out in 1996:

$$E = 0.53 \frac{R_g}{\lambda}. \qquad (1.6)$$

It is noted that all these formulas give the evapotranspiration in mm/day and the abbreviations are as follows.

Δ – represents the slope of the saturation curve in hPa/°C and is given by the formula:

$$\Delta = 33.8639\,(0.05904\,(0.00738T + 0.8072)2 \quad 0.0000342), \qquad (1.7)$$

In kPa/°C;

γ– represents the psychometric constant in hPa/°C and is given by the formula:

$$\gamma = 0.00163 \frac{P}{\lambda}, \qquad (1.8)$$

in kPa/°C;
R_g– represents the total radiation in cal/cm ^{2} / day;
T – represents the temperature of the air in °C;
R_n– represents the Net radiation in cal/cm ^{2} / day and is given by the formula of RIOU:

$$R_n = R_g(1 \quad \alpha) \quad \sigma T4\,(0.4 \quad 0.05\sqrt{e})(0.5 + 0.5 \frac{S}{S_0}), \qquad (1.9)$$

With α = 0.04 which is the albedo free face, σ – the Boltzmann constant, S – duration of the sun radiation observed, s_0– maximum duration of the sun radiation (theoretical);

λ – represents the latent evaporation heat and is given by the formula:

$$\lambda = 595 - 0.51T, \qquad (1.10)$$

In MJoules/kg;
f – Relative moisture of the air in %;
T_m – the average temperature of the air in °C;
T_D – the temperature of the Dew Point in °C;
F – Represents the decrease with the altitude of the density of the air and is given by the formula:

$$F = 1 - 8.7 \cdot 10 \quad 5z\,; \qquad (1.11)$$

P – Represents the atmospheric pressure (in hPa) and given by the following formula according to altitude:

$$P = 1013 \quad 0.1055z, \qquad (1.12)$$

Where z is the altitude in meter;

u is the speed of the wind in m/s.

It is obvious that the formulas based on the method of radiation are not easily exploitable in our developing countries because they contain parameters which are not observed locally due to the absence of suitable equipments which are excessively expensive and the lack of qualified personnel in the majority of stations. These parameters are in instance the total and net radiations. Some of these parameters can be given starting from the knowledge of the temperature of the air, of the air relative moisture, the atmospheric pressure, the vapor tension in the air. But it should be said that many of our stations do not take them into account in their observations for aforesaid reasons. Concerning the formulas based on the method of mass transfer, the following ones are often used, (Benoit, 2003, SAIDATI *et al*.. 2006).

The formula of Dalton worked out in 1802:

$$E = a(Es - Ea), \qquad (1.13)$$

With a = 15 for a not very deep lake and a = 11 when it is deep.

The formula of Fitzgerald worked out in 1886:

$$E = (4 \cdot 0.199u)(Es - Ea), \qquad (1.14)$$

Where u is the speed of the wind in inches/hour

The formula of Meyer worked out in 1915:

$$E = 11(1 + 0.1u)(Es - Ea), \qquad (1.15)$$

The formula of Horton worked out in 1917:

$$E = 0.4\,(2 \quad e \quad 2u(Es - Ea)), \qquad (1.16)$$

The formula of Penman worked out in 1948:

$$E = 0.30\,(1 + 0.2u)(Es - Ea), \qquad (1.17)$$

The formula of Romanenko worked out in 1961:

$$E = 0.0018\,(Ta + 25)2(100 \quad f), \qquad (1.18)$$

Ta is the temperature of the air and f its relative moisture in %.

It must be noted that all these formulas give E in mm/month and that almost all formulas contain the difference $E_S - Ea$ where E_S is the vapor saturation tension determined from the temperature of acting surface (here terrestrial surface) and E_a – the vapor tension determined from the temperature of the air. Almost all are related to the wind speed. It is thus clear that these two factors play a determining role in this method. Last, the exploitation of these formulas may be performed by personnel with elementary knowledge. Their realization requires only knowledge of three parameters, namely the temperatures on the acting surface and of the air, and the wind speed. And these parameters are observed in many stations of our developing countries although their time series are not always regular in certain localities. This explains why the authors of this article based their analysis on the method of mass transfer to estimate the minimal value of the index of the hydrous deficit of the Earth-Atmosphere system in order to compute the evapotranspiration in the localities of the zone of study. As $E_s - E_a$ is given starting from the temperatures of two different bodies: Earth and air, and that this difference is similar to that of the formula of computation of the deficit of vapor saturation in the air, the authors called it index of the hydrous deficit of the system Earth-Atmosphere on which this work is based.

It is obvious that this index is an always positive quantity and its value is higher, the more the phenomenon of evapotranspiration is intense in the locality considered. For the calculation of the evapotranspiration, FAO (UN Food and Agriculture Organization) recommends for instance, the use of the two following formulas, without reference to the zone of study, namely the formulas of Penman-Monteith and Hargreaves which are given respectively by the following expressions:

$$E = \frac{\Delta(R_n \quad G) + \rho c_p \dfrac{(E_s \quad E_a)}{r_a}}{\Delta + \gamma(1 + \dfrac{r_s}{r_a})}, \qquad (1.19)$$

$$E = 0.0023\frac{R_a}{2.45}(T_m + 17.8)\sqrt{T_d}, \qquad (1.20)$$

where G is the heat flux of Earth, ρ– the average density of air, c_p–the specific heat of the air at constant pressure, r_a– the aerodynamic resistance of the air, r_s– the resistance of vegetable cover, R_a– extraterrestrial radiation in MJoules/(m^2 .day) and given by the formula:

$$R_a = 37.6dr\,(oms \cdot sinf \cdot sindd + cosf \cdot cosdd \cdot sinoms) \cdot 23.89 \cdot 4.186 \cdot 10 \quad 2,$$

(R_a Must be expressed in evaporation equivalent, i.e. in mm/day),

$F = \frac{\pi}{18\ 0}$- latitude in radians,

$dr = 1 + 0.033cos(0.0172doy)$ $distance\ Eart$ $Sun\ dd = 0.409sin(0.0172 + doy \quad 1.39)$ –

Solar declination is $oms = arctan(\frac{-nn}{\sqrt{-nn \cdot nn+1}}) + 1.5708$– half of the duration of the day; $nn = (\ tan(0.2115)tan(dd))$ – solar angle at dawn/ twilight $Tm = \frac{T_{max}+T_{min}}{2}, Td = Tmax \quad Tmin$, where T_{max} and T_{min} are respectively, the maximum and minimum temperatures of the air.

As one can notice it is not easy to use these two formulas because one needs to know many parameters which are not often given in our developing countries. One notes that the values of some of these parameters presented in specific tables are available in hydro- meteorological services of various countries. However, their exploitation is not always easy because much of intermediate calculations and interpolations have to be carried out. This is not easy for our not qualified personnel very often accustomed only with elementary operations. It is thus imperative to work out a simplified, requiring little of data and exploitable methods in our developing countries in general, and in the zone of study in particular. The principal assumption is as follows. The temperature of terrestrial surface is always higher than that of the air. And the more one moves away in altitude, the more temperature of the air decreases. As no meteorological station in the zone of study has data on the temperature of terrestrial surface, we compared this one to the maximum temperature of the air. Being given that this maximum temperature of the air would be equal to that of terrestrial surface (in the zone of study), it is obvious that the results obtained could be regarded only as the minimal values of the index of the hydrous deficit of the system in question. It is clear that this approach will be gradually improved as far as the data of observations allow it.

Our work is structured as follows. The second paragraph is devoted to materials and methods. It comprises three parts, namely: weather data, the methodology and the calculation algorithm. The third paragraph presents the results and their analyses. Here two components are examined, namely the annual and monthly estimates of the index of the hydrous deficit of the system Earth-Atmosphere. A conclusion comprising some recommendations and prospects closes this paper.

Data, methodology and computations algorithm

Data

Geographical location

The area of study lies between 15.0°-21.5°E and 8.0°-14.0°N. It is characterized by sudanian climate. According to not published documents of the Ministry of Environment and Water of Chad (MEW), one records an average of 800 mm to1200 mm of rain fall per annum, with a yearly absolute maximum temperature of the air around 45.0°C and a maximum relative moisture of the air close to 96%. The coldest period of the year generally extends from December to February with 11.0°C-22.0°C and the hotter from Mars to June with 39.0°C-45.0°C. During these last decades, this climate experiences some evolutionary degradation. Indeed, according to the same source, the rainy seasons are reducing year after year whereas the thermometers record increasingly high temperatures, exceeding 50.0°C during the period from April to June in some cities of the country, N'Djamena for instance.

Meteorological data

From 1975 to 2008, Chad practically did not know peace. This generated many problems among others the following: a weak cover of the country in weather observation stations a personal that does not possess the required qualification, especially in the countryside, very irregular time series of the data, and certain observations are not carried out for lack of measurement apparatus. The examination of the country's climatic files indicates that the data on relative temperatures and moisture of the air cover more or less regularly some localities, in particular in the southern part of the country. We exploit these data. They are not firsthand data. They have been submitted already to some digital processing and are presented in the form of tables on monthly and annual averages. They cover different periods which vary from 10 to 35 years, according the station concerned. These localities are: Abéché, Mongo, Bokoro, N'Djamena, Bongor, Laï, and Sarh.

Figure 2.1 Presents geographical position of the stations.

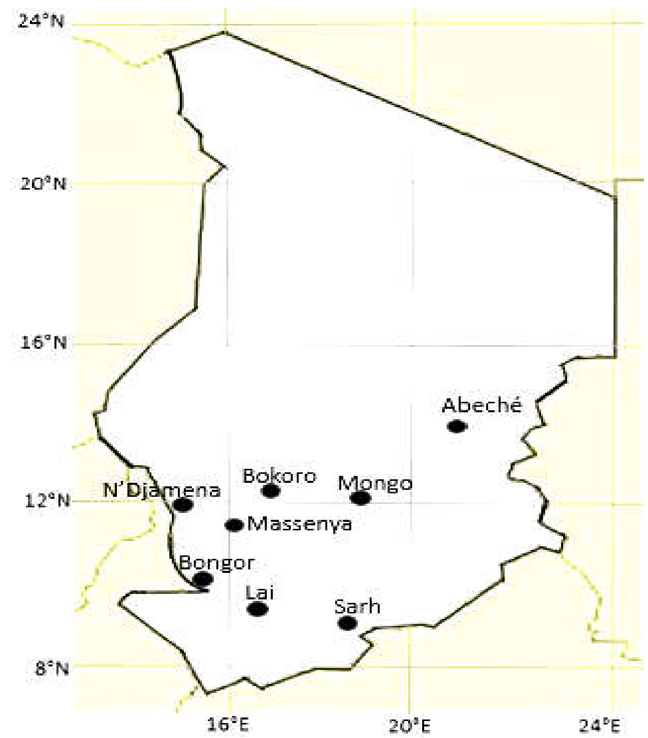

Figure 2.1. Localities of study

Methodology

The formulas allowing estimating the evapotranspiration of a given surface on the basis of the method of mass transfer can be summarized by the following expression, (BRUTSSART, 1982):

$$W = \alpha f(u)(Es - Ea) \quad (2.1)$$

where W is the speed of evapotranspiration, generally in mm/day, α– an empirical coefficient, $f(u)$ – a function of wind speed u in m/s, E_S – the vapor saturation tension determined from the temperature of acting surface, in hPa, E_a– the partial vapor tension determined from the temperature of the air, in hPa, E_S-Ea is the hydrous deficit of the Earth-Atmosphere system. The larger this last is, the more W is significant. One notes that all the terms of formula (2.1) are positive. Knowing that the data on the temperature of terrestrial surface being lacking, they will be replaced by those of the maximum temperature of the air. This one generally varies in the range of 40.0°C-50.0°C. As there is no meteorogical station that recorded a temperature above 65.0°C, we assume that the temperature of terrestrial surface in the zone of study does not exceed this value and it varies in the range 40.0°C-65.0°C.

Computations algorithm

The Clausius–Clapeyron equation which establishes a relation between temperature and the vapor saturation tension may be written in the form:

$$Ln\left(\frac{E}{E0}\right) = \left(\frac{L0}{R}\right)\left(\frac{1}{T0} \quad \frac{1}{T}\right), \quad (2.2)$$

Where T_0 and $E_0 = E(T_0)$ are initial values of the temperature and of the vapor saturation tension of water, in Kelvin and hPa respectively, T and E=E (T) the same parameters with an unspecified temperature T, constant R=460 KJ/(Kg.·K) is the universal ideal gas constant.

From (2.2), one obtains the following practical formula,

$$E = E0 \cdot \frac{108.61503t}{273.15 + t}, \quad (2.3)$$

Obtained by posing $T_0 = 273.15$ K, $L_0 = 2.5 \cdot 10^6$ J/Kg, T – the temperature in °C and $E_0 = 6.10753$ hPa.

One the basis of (2.3) and by taking into account the above expressions, we have:

$$Es = E0 \cdot 108.61503tmax / (273.15 + tmax),$$
$$Ea = E0 \cdot 108.61503tmin / (273.15 + tmin) \quad (2.4)$$

Knowing the relative moisture value f of the air:

$$f = \frac{ea}{Ea}, \quad (2.5)$$

One obtains the value of the vapor tension of water in the air:

$$ea = Ea \cdot f. \quad (2.6)$$

One deduces from it finally the estimate of the required index of the hydrous deficit of Earth-Atmosphere system

$$Es - ea. \quad (2 \quad 7)$$

Finally the 40.0°C-65.0°C interval is divided into smaller intervals of 5.0°C each, and in each one it is carried out a year analysis of the maximum error generated by this approach, in the estimate of the saturation vapor tension of water starting from the temperature of terrestrial surface.

RESULTS AND DISCUSSION

The minimal annual average values of the index of the hydrous deficit of Earth-Atmosphere system are presented in Table 3.1.

This reveals that for all the localities of study these values are varying between 40.00-74.00 hPa, except for the localities of Sarh where they vary between 2.93-50.00 hPa and Mongo where they oscillate between 19.00-25.00 hPa towards the end of the period of study (1998-2002). The highest value is 73.67 hPa was recorded in Laï in 1996, the smallest value 2.93 hPa, in Sarh in 1992. In all the localities, this parameter vary year by year in saw teeth, with alternative amplitudes: 26.21 hPa for Abéché, 33.61 hPa for Laï, 42.36 hPa for Mongo, 13.14 hPa for N'Djamena, 47.13 hPa for Sarh. Bokoro and Bongor are left aside because their data cover hardly half of the period.

One classifies these values in three qualified classes as follows: $ES \quad Ea = 40.00$ hPa, (weak class); 40.00<E_S- Ea ≤50.00 hPa (middle class); E_S - E_a >50.00 hPa (strong class). This leads to the following conclusions. For almost all the periods of study the intensive evapotranspiration was in Abéché, Laï and Bokoro; weak in Sarh only in the middle of the period of study and in Mongo at the second half of that period.

Sarh are taken into account because they have data covering more than half of the period of study. The results of these simulations are presented in the following tables.

Station of Abéché

The exponential and linear models gave respectively the expressions:

$y1(t) = 54.95 \cdot 10 \quad 0.00431t, \qquad y2(t) = \quad 0.47t\, 55.40$

By posing $y_{1,th}$ and $y_{2,th}$ the theoretical values resulting respectively from these two models, y_{exp}– values of Table 3.1 considered as experimental, $|e|= |y_{th} \quad y_{exp}|$- the absolute value of the difference between the theoretical and experimental values of the parameter considered which, will be called in the following degree of fidelity of the model, $|e.r.| = \left|\frac{y_{th}-y_{exp}}{y_{exp}}\right|$- the absolute value of the relative error of these two values, we obtain the Table 3.2.

Table 3.1. Minimal Annual average been worth of the index of the hydrous deficit of the system Ground Atmosphere, E_S - E $_{has}$ in hPa/an, the localities of study

	Abéché	Bokoro	Lay	Mongo	Djaména	Sarh	Bongor
1990	62.88	-	54.02	-	55.97	4.93	-
1991	52.55	56.46	51.80	56.46	53.57	4.10	-
1992	56.67	41.62	50.42	52.34	55.50	2.93	-
1993	59.28	58.93	54.17	54.93	55.54	4.10	-
1994	57.33	57.76	51.38	44.04	52.64	15.90	-
1995	52.69	60.25	49.59	47.35	53.73	16.83	52.60
1996	-	-	73.67	47.14	57.48	49.78	64.65
1997	-	-	40.06	-	51.44	50.06	49.80
1998	42.92	-	43.94	23.78	51.10	21.64	48.47
1999	69.13	-	51.63	24.66	60.34	16.51	48.98
2000	-	-	-	61.80	47.20	42.09	54.70
2002	49.84	-	61.03	19.44	57.30	34.00	47.57

Table 3.2. Comparative table of the experimental and theoretical values of the minimal index of the hydrous deficit of the system considered in Abéché Station

T	-6	-5	-4	-3	-2	-1	2	3	6
y_{exp}	62.88	52.55	56.67	59.28	57.33	52.69	42.92	69.13	49.84
$y_{1,HT}$	58.32	57.75	57.18	56.61	56.05	55.50	53.87	53.34	51.77
$\|e\|1$	4.56	5.20	0.51	2.67	1.28	2.81	10.95	15.79	1.93
$\|e.r.\|1$	7%	10%	1%	5%	2%	5%	26%	23%	4%
$y_{2,HT}$	58.22	57.75	57.28	56.81	56.34	55.87	54.46	53.99	52.58
$\|e\|2$	4.66	5.20	0.61	2.47	0.99	3.18	11.54	15.14	2.74
$\|e.r.\|2$	7%	10%	1%	4%	2%	6%	27%	22%	5%

Figure 3.1 shows the temporal variation of this parameter. Its examination does not allow us to find the functional relation that describes best this variation. Some standard figures built in different scales and the analysis of the points clouds configurations obtained enabled us to propose two forms of functional relation for this temporal variation, namely the exponential form whose mathematical expression is:

$$y(t) = A10^{\alpha t}, \qquad (3.1)$$

And the linear form whose mathematical expression is:

$$y(t) = at + b, \qquad (3.2)$$

Where A, α, *a,* and *B* are constant to be determined by treating the data of Table 3.1 by the method of least squares; *t* is time and y– the hydrous deficit of the system. To avoid working with great numbers, we introduced a fictious zero time, posing that the year 1996 correspond to time *t*=0. During this work of modeling, only the localities of Abéché, Laï, N'Djamena and

Station of Lay

The exponential and linear models gave respectively the expressions:

$y1(t) = 52.27 \cdot 100.00124t, \; y2(t) = 0.19t + 53.03$

Station of N'Djamena

The exponential and linear models gave the expressions respectively:

$y1(t) = 54.08 \cdot 10 \quad 0.00080t, y2(t) = 3.59t + 55.81$

Station of Sarh

The exponential and linear models gave respectively the expressions:

$y1(t) = 15.86 \cdot 100.09663t, \qquad y2(t) = 3.24t + 23.26.$

Table 3.3. Comparative table of the experimental and theoretical values of the minimal index of the hydrous deficit of the system considered. Station of Laï

T	-6	-5	-4	-3	-2	-1	0	1	2	3	6
y_{exp}	54.02	51.80	50.42	54.17	51.38	49.59	73.67	40.06	43.94	51.63	61.03
$y_{1,HT}$	51.38	51.53	51.68	51.82	51.97	52.12	52.27	52.42	52.57	52.72	53.17
$\|e\|1$	2.64	0.27	1.26	2.35	0.59	2.53	21.40	12.36	8.63	1.09	7.86
$\|e.r.\|1$	5%	1%	2%	4%	1%	5%	29%	31%	20%	2%	13%
$y_{2,HT}$	51.89	52.08	52.27	52.46	52.65	52.84	53.03	53.22	53.41	53.60	54.17
$\|e\|2$	2.13	0.28	1.85	1.71	1.27	3.25	20.64	13.16	9.47	1.97	6.86
$\|e.r.\|2$	4%	1%	4%	3%	2%	7%	28%	33%	18%	4%	11%

Table 3.4. Comparative table of the experimental and theoretical values of the minimal index of the hydrous deficit of the system considered. Station of N'Djamena

T	-6	-5	-4	-3	-2	-1	0	1	2	3	4	6
y_{exp}	55.97	53.57	55.50	55.54	52.64	53.73	57.48	51.44	51.10	60.34	47.20	57.30
$y_{1,HT}$	54.68	54.58	54.48	54.38	54.28	54.18	54.08	53.98	53.88	53.78	53.68	53.49
$\|e\|1$	1.29	1.01	1.02	1.16	1.64	0.45	3.40	2.54	2.78	6.56	6.48	3.81
$\|e.r.\|1$	2%	2%	2%	2%	3%	1%	6%	5%	5%	11%	14%	7%
$y_{2,HT}$	34.27	37.86	41.45	45.04	48.63	52.22	55.81	59.40	62.99	66.58	70.17	77.35
$\|e\|2$	21.70	15.71	14.05	10.50	4.01	1.37	1.67	7.96	11.89	6.24	22.97	20.05
$\|e.r.\|2$	39%	29%	25%	19%	8%	3%	3%	15%	23%	10%	49%	35%

Table 3.5. Comparative table of the experimental and theoretical values of the minimal index of hydric deficit of the system considered Sarh station

T	-6	-5	-4	-3	-2	-1	0	1	2	3	4	6
y_{exp}	4.93	4.10	2.93	4.10	15.90	16.83	49.78	50.06	21.64	16.51	42.09	34.00
$y_{1,HT}$	4.17	5.21	6.51	8.14	10.16	12.70	15.86	19.81	24.75	30.92	38.62	60.27
$\|e\|1$	0.76	1.11	3.58	4.04	5.74	4.13	33.92	30.25	3.11	14.41	3.47	26.27
$\|e.r.\|1$	15%	27%	122%	98%	36%	25%	68%	60%	14%	87%	8%	77%
$y_{2,HT}$	3.82	7.06	10.30	13.54	16.78	20.02	23.26	26.50	29.74	32.98	36.22	42.70
$\|e\|2$	1.11	2.96	7.37	9.44	0.88	3.19	26.52	23.56	8.10	16.47	5.87	8.70
$\|e.r.\|2$	23%	72%	252%	230%	6%	19%	53%	47%	37%	100%	14%	26%

Table 3.6. Values of the monthly index of the atmospheric hydrous deficit $E_S - E_a$ in hPa/month, in some localities of study

	Jan.	Feb.	March	April	May	June	July.	August	Sept.	Oct..	Nov..	Déc.
Abéché	44.03	51.77	64.70	74.13	69.73	63.33	47.42	36.58	49.48	57.27	50.91	44.63
Bokoro	34.97	39.06	52.56	61.57	58.08	44.26	33.00	25.12	33.53	42.21	39.69	33.56
Bongor	51.55	58.74	75.01	75.96	63.97	44.33	31.80	30.95	33.62	42.79	55.14	49.56
Lay	58.11	66.28	77.96	71.67	54.79	43.58	32.66	30.07	33.69	44.33	59.38	54.61
Mongo	46.86	54.11	67.37	69.59	54.40	48.73	33.15	24.79	35.22	47.34	48.14	43.08
Djaména	36.47	42.56	52.50	58.24	52.82	43.88	31.14	23.75	30.10	44.67	44.93	38.16
Sarh	21.29	25.37	29.37	29.47	23.38	17.41	13.56	12.41	13.68	16.98	20.45	20.68

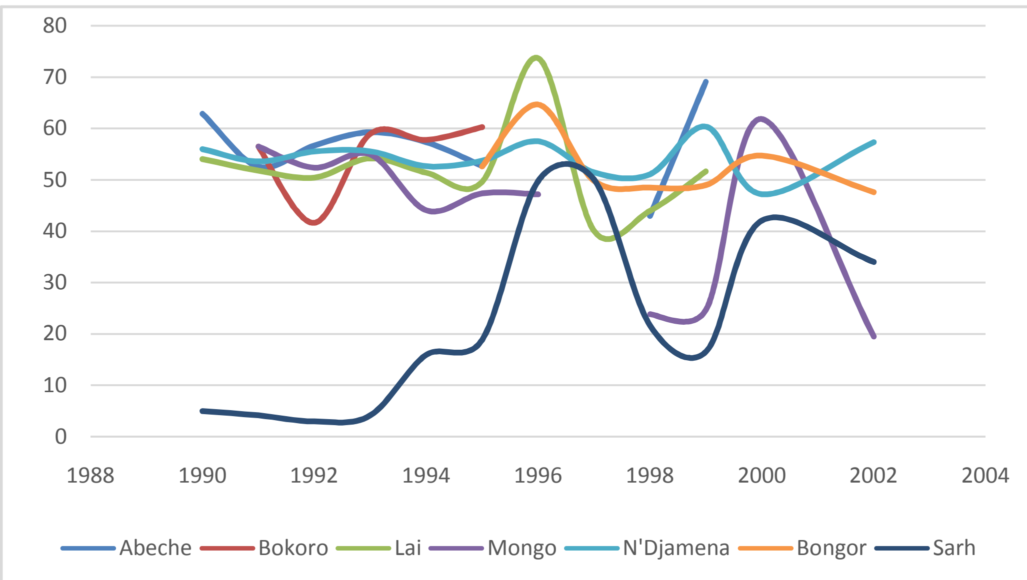

Figure 3.1. Temporal variation of the values of the annual index of the atmospheric hydrous deficit in the localities of study

The analysis of the results of Tables 3.2-3.5 values makes it possible to conclude that the two models give overall acceptable estimates with acceptable degree of fidelity and those of the relative error seldom exceeding 30% except for the locality of Sarh, where these values are, generally higher than 30%, going even to beyond 250%.

the masses of humid air from Atlantic Ocean to the opposite direction. The locality of Sarh is characterized by the smallest values of this index during all the year. This could be explained by the proximity of some rivers as Chari which attenuates the atmospheric hydrous deficit.

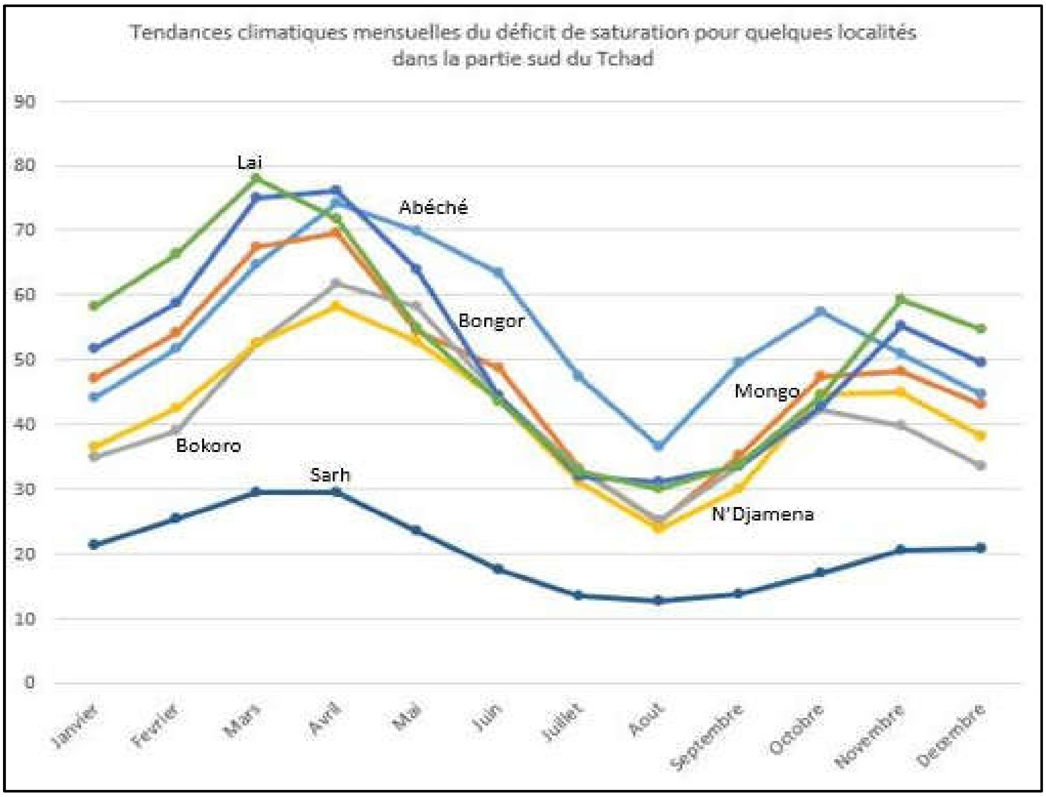

Figure 3.2. Variation of the monthly estimates of the hydrous deficit

The localities where the values of these parameters of judgment are higher experienced great irregularities in their chronological series. The authors estimate that this situation constitutes the principal cause of the disparity of the results in certain stations. These models indicate a general tendency to reinforce temporal series of the hydrous deficit index of Earth-Atmosphere system in the area of study because the functions obtained in these models are increasing, except for the locality Abéché. Table 3.6 presents the monthly minimal average values of the hydrous deficit index of Earth-Atmosphere system in the zone of study and Figure 3.2 shows its temporal variation in the various localities considered. It is deduced from this table that the maximum absolute values of this parameter, 77.96 hPa, was recorded in Laï in March and its minimal absolute values, 12.41 hPa, in Sarh in August. From January to April (and once in March), the temporal variation of this parameter is increasing in all the zone of study, which implies intense yearly evapotranspiration at this period of the year. From April to August this variation is decreasing, which indicates a reduction of the evapotranspiration in the area. This period is followed by a period of increasing values of the index with relative maxima between October and November. Temporal variation is explained among other, by seasonal movements of the masses of air. Indeed, at the beginning of September the Intertropical Convergence Zone migrates gradually towards the equator bringing masses of dry air from the Sahara desert till the south of Chad, which explains the increase of the hydrous deficit index. Starting from May the Intertropical Convergence Zone goes up north, which brings

Conclusion

The present study, the first of its kind concerning Chad in general and this agricultural area in particular, launches a series of other works which will precise the results obtained here and will help to set up an adequate method of the evapotranspiration determination for instance. It gives a minimal size order of the hydrous deficit index for Earth-Atmosphere system. This is a very significant factor in the evaluation of the evapotranspiration whose impacts in agriculture are considerable. It also makes it possible to assess the trends to increase almost everywhere (except in one locality) of the temporal variation of this parameter. The modeling and established functional relations should enable to reconstitute with a good precision the missing climatic values of this index in particular. In general a similar work could be performed to supplement the missing data of other weather parameters in the zone.

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