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Comparison of three methods for estimating the global solar radiation of Faya-Largeau in the Saharan zone, Chad

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Abstract - *In this work, we make a confrontation between measured values of the solar radiation given by NASA and those estimated by the mathematical models suggested in the literature. The chosen mathematical models are those of the model of Angstrom, Allen and the model of Sabbagh which are described as the best models. The three methods used the root mean square error (RMSE),mean bias error(MBE), mean percentage error(MPE) and nash- sutcliffe equation(NSE) was compared with failure analysis. The site of Faya-Largeau has been chosen as reference. The comparative study of the obtained results showed that the model of Sabbagh presents a best estimation of the global solar radiation with a value of 6.013 kWh/m²/day in particular for an incidence on horizontal level. Well cavity, it arises that the site of Faya-Largeau being in the Saharan zone of Chad has a good solar potential for the exploitation of photovoltaic solar energy.*

Résumé - *Dans ce travail, nous faisons une confrontation entre les valeurs mesurées du rayonnement solaire donné par la NASA et celles estimées par les modèles mathématiques suggérés dans la littérature. Les modèles mathématiques choisis sont ceux du modèle d'Angstrom, Allenet du modèle de Sabbagh qui sont décrits comme les meilleurs modèles. Les trois méthodes ont utilisé l'erreur quadratique moyenne (RMSE), l'erreur de biais moyenne (MBE), l'erreur de pourcentage moyen (MPE) et l'équation de Nash- Sutcliffe (NSE) ont été comparées à l'analyse de défaillance. Le site de Faya-Largeau a été choisi comme référence. L'étude comparative des résultats obtenus montre que le modèle de Sabbagh présente une meilleure estimation du rayonnement solaire global avec une valeur de 6.013 kWh/m²/jour en particulier pour une incidence au niveau horizontal. Bien cavité, il s'avère que le site de Faya-Largeau étant dans la zone saharienne du Tchad a un bon potentiel solaire pour l'exploitation de l'énergie solaire photovoltaïque.*

Keywords: Global solar radiation - Faya-Largeau - Sabbagh - Angstrom - Allen.

1. INTRODUCTION

The principal source of the most significant energy comes from the solar radiation which is one of the determining factors of change of climatic [1, 2].Thus, considering the growth of the population and with the aim of protects the environment, reduction of gases for purpose of greenhouse, one must think of the interest which can bring renewable energies such as solar energy [3]. The majority of the solar devices of photovoltaic conversion require the knowledge of the solar radiation available for a site given on a horizontal or inclined level [4-6].

These last years, the solar energy, which is characterized by an absence of pollution and, by its availability, is the subject of a great interest. Indeed, the operating systems

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which use this form of energy require a light maintenance and have a good reliability of operation. They are an increasingly increased autonomy, an extreme resistance to the natural conditions (temperature, moisture, wind, corrosion, etc), and thus a great longevity. It appears that solar energy can bring real solutions to the various difficulties which currently arise concerning the climatic changes, the energy crises....

There are two kind of solar energy systems: the photovoltaic systems for the production of electricity and the thermal systems (solar-fired heaters) for the production of hot water, field where she particularly experiences a considerable development in the sector of the habitat [7].

With 80% rural population, and a total absence of a grid system of electricity, Chad can hope on renewable energies to ensure its production and its energy independence everywhere. Between 2 to 4% of the population has access to electricity. However, energy is a true engine of development as well as the financial and human resources [8].

The meteorological stations installed in Chad haven't instruments to measure the solar potential. The available data are limited to empirical measurements of the sunshine duration. Chad hasn't materials and specialists to evaluate the solar and wind potentials and to establish their maps. That is why some of measurements are obtained by Satellite but not over a long time. Until today any research has been led in Chad on the evaluation of the solar potential.

For that, the object of our work concerns the comparison of two methods to evaluate of the global solar radiation of Faya-Largeau in the Saharan zone of Chad from which the drank is the choice of the most suitable model. Thus, this comparison will enable us to have an idea on solar energy available for a good dimensioning of a solar system.

2. DATA COLLECTION

Table 1 presents the weather data used in this work coming from the Directorate General of the meteorology of Chad in order to consider the irradiation solar total. It is about the duration of sunning during 17 years, Relative humidity during 22 years, maximum temperature for 21 years, minimal temperature during 22 years and average temperature for 21 years. These data are used in the equations considering the irradiation solar total of Faya-Largeau.

Table 1: Monthly mean daily hours of bright sunshine maximum temperature, relative humidity

Month	Tm (°C)	DI (hours)	HR (%)	Tmaxaverage (°C)	Tminaverage (°C)
January	20.01	10.144	20.9	26.43	13.5
February	22.20	10.413	16.3	29.4	15.1
March	25.98	9.793	13.8	33.59	18.4
April	30.74	9.837	12.9	39.07	22.5
May	32.98	10.041	17.6	41.0	25.0
June	34.07	9.988	18.2	42.09	26.1
July	33.36	8.194	30.1	41.02	25.9
August	33.05	7.235	36.5	40.16	26.0
September	32.8	8.652	20.4	39.75	26.0
October	29.51	10.113	17.1	36.51	22.6
November	24.48	10.406	19.4	31.07	18.0
December	20.96	10.313	21.3	27.56	14.5

3. PRESENTATION OF THE STUDIED MODELS

3.1 Modeling of the radiation out of atmosphere

The extraterrestrial solar radiation is given by the following equations [9],

$$H_0 = \frac{24}{\pi} I_{sc}\left(1+0.33\cos\left(\frac{360 D_n}{365}\right)\right)\times\left(\cos L \cos\delta \sin\omega_s + \frac{2\pi\omega_s}{360}\sin L \sin\delta\right) \quad (1)$$

where ω_s is the time angle defined by,

$$\omega_s = \cos^{-1}\left(-\tan L \tan\delta\right) \quad (2)$$

and δ is the solar variation defined by,

$$\delta = 23.45 \sin\left(\frac{360(284 + D_n)}{365}\right) \quad (3)$$

3.2 Modeling of the total radiation on a horizontal level by the model of Angstrom

Angstrom was the first to propose an ideal model (linear model) to estimate the total horizontal solar radiation with in entry the data over the duration of the sunshine duration. Prescott [10] and Page [11] improved this model and considered the total horizontal sunshine duration according to the relation[12, 13],

$$\frac{H}{H_0} = a + b\left(\frac{S}{S_0}\right) \quad (4)$$

Where $a = -0.110 + 0.235\cos\varphi + 0.323\left(S / S_0\right)$ (5)

$$b = 1.449 - 0.553\cos\varphi - 0.694\left(S / S_0\right) \quad (6)$$

and $S_0 = \frac{2}{15}\cos^{-1}\left(-\tan L \tan\delta\right)$ (7)

3.3 Total radiation on a horizontal level by the model of Sabbagh

Sabbagh obtained the total solar radiation according to the duration of the sunstroke, the relative humidity, the maximum temperature, the altitude and the geographical localization (longitude, latitude). He used the following relations [14],

$$H = 1.530 K \times \exp\varphi\left(\frac{S}{S_0} - \frac{HR^{1/3}}{100} - \frac{1}{T_{max}}\right) \quad (8)$$

$$K = 100\left(n T_{max} + \psi_{ij}\cos(\varphi)\right) \quad (9)$$

$$n = \frac{1}{(1 + 0.1\varphi)} \quad (10)$$

Where DI, HR, and T_{max} are respectively the monthly average per day of the duration of the sunstroke, the relative humidity and the maximum average temperature of the considered month.

3.4 Total radiation on a horizontal level with Model of Allen

Allen [15, 16] estimated monthly mean of the global solar radiation as a function of H_0, monthly mean of the maximum temperature (T_M), and the monthly mean of the minimum temperature (T_m) as,

$$\frac{H}{H_0} = K_r (T_M - T_m)^{0.5} \tag{11}$$

Where, K_r is defined as,

$$K_r = K_{ra} \left(\frac{P}{P_0} \right)^{0.5} \tag{12}$$

Following Lunde [17], $K_{ra} = 0.17$ and P/P_0 may be defined as,

$$\frac{P}{P_0} = \exp\left(-0.0001184h\right) \tag{13}$$

Where P and P_0 are the values of local and standard atmospheric pressure, respectively, and h is the altitude of the place in meters.

4.PERFORMANCE EVALUATIONS OF TWO METHODS

In order to compare the data of the solar radiation provided by NASA with those which presented in paragraph 2, we have created for each studied model a program under Matlab and Excel.

Several statistical indicators used in the literature [18-20], enabled us to confront the calculated data by the mathematical models and those measured by the NASA.

The used indicators are: RMSE, MBE, MPE and NSE.

The RMSE indicator [21]

The RMSE (Root Mean Square Errors) is a measurement of the variation of the computed values, according to each model around the measured values. The model is the best when his RMSE value is the smallest. It is defined by the relation,

$$\text{RMSE} = \sqrt{\sum_{i=1}^{n} \frac{(H_{ic} - H_{im})^2}{n}} \tag{14}$$

n represent the number of the month.

The MBE indicator [22]

The MBE (Mean bias error) which is the error of average skew is calculated starting from the relation,

$$\text{MBE} = \sum_{i=1}^{n} \frac{(H_{ic} - H_{im})}{n} \tag{15}$$

An indication gave the average deviation of the computed values compared to the measured values. A positive value indicates an over estimation and a negative value indicates an undervaluation.

The MPE indicator [22]

The MPE (Mean Percentage Error) is defined by the relation,

$$MPE(\%) = \frac{1}{n} \times \sum_{i=1}^{n} \frac{(H_{ic} - H_{im})}{H_{im}} \times 100 \qquad (16)$$

For this indicator, an error expressed as a percentage ranging between -10% and +10% are acceptable for the model [22].

The NSE indicator [23]

The NSE (Nash-Sutcliffe Equation) represents a measure of the precision of the model results. A model is more efficient when NSE is closer to 1 [23]. The NSE is defined by the relation,

$$NSE = 1 - \frac{\sum_{i=1}^{n} (H_{im} - H_{ic})^2}{\sum_{i=1}^{n} (H_{im} - \overline{H_m})^2} \qquad (17)$$

Where $\overline{H_m}$ is the mean measured global radiation.

5. RESULTS AND DISCUSSIONS

The estimation of the solar potential of Faya-Largeau, delimited by the latitude of 17°55 and longitude of 19°7, is carried out by using the software Excel and Matlab. The used of the two presented mathematical methods enabled us to evaluate the solar potential of the considered site.

Table 1 presents the obtained results using the method of Angstrom. It is noticed that the average values of the non constant parameters has a and b are respectively 0.390 and 0.328.

Thus, for the various months of the year, one observes the smallest value of a, within August ($a = 0.322$), and his greatest value within February ($a = 0.414$). For the parameter b, his smallest value is observed within February ($b = 0.276$) and his greatest value within August ($b = 0.475$).The highest value of the sunshine duration is 10.413(h) (in February) and his lowest value is 7.235(h) (in August).

Concerning the astronomical duration of the day it is 11.199 (h). In addition the average of the extraterrestrial radiation is 8.190 kWh/m^2/day, the rate of sunstroke is 0.857, the index of clearness is 0.666 and the total solar radiation is 5.457 kWh/m^2/day.

Table 2: Angstrom method

Months	a	b	S(h)	S_0(h)	H_0	H(Wh/m^2/day)	S/S_0(-)	H/H_0(-)
January	0.406	0.295	10.144	11.206	8.210	5.522	0.905	0.6727
February	0.414	0.276	10.413	11.170	8.112	5.450	0.932	0.6719
March	0.396	0.316	9.793	11.206	8.210	5.519	0.874	0.6723
April	0.397	0.313	9.837	11.194	8.177	5.498	0.879	0.6725
May	0.403	0.301	10.041	11.206	8.210	5.523	0.896	0.6727
June	0.402	0.304	9.988	11.194	8.177	5.500	0.892	0.6727
July	0.350	0.415	8.194	11.206	8.210	5.365	0.731	0.6535
August	0.322	0.475	7.235	11.206	8.210	5.161	0.646	0.6286
September	0.363	0.386	8.652	11.194	8.177	5.412	0.773	0.6619
October	0.405	0.296	10.113	11.206	8.210	5.522	0.902	0.6727
November	0.414	0.278	10.406	11.194	8.177	5.495	0.930	0.6720
December	0.411	0.284	10.313	11.206	8.210	5.520	0.920	0.6723
Average	0.390	0.328	9.594	11.199	8.190	5.457	0.857	0.6663

Table 3: Sabbagh method

Months	S(h)	S_0(h)	HR (%)	T_{max}(°C)	S/S_0(-)	H(kwh/m^2/day)
January	10.144	11.206	20.9	26.43	0.905	4.521
February	10.413	11.170	16.3	29.4	0.932	5.163
March	9.793	11.206	13.8	33.59	0.874	5.845
April	9.837	11.194	12.9	39.07	0.879	6.820
May	10.041	11.206	17.6	41.0	0.896	7.065
June	9.988	11.194	18.2	42.09	0.892	7.226
July	8.194	11.206	30.1	41.02	0.731	6.483
August	7.235	11.206	36.5	40.16	0.646	6.102
September	8.652	11.194	20.4	39.75	0.773	6.527
October	10.113	11.206	17.1	36.51	0.902	6.294
November	10.406	11.194	19.4	31.07	0.930	5.377
December	10.313	11.206	21.3	27.56	0.920	4.734
Average	9.594	11.199	20.37	35.65	0.857	6.013

Table 3 presents the average values of the parameters of the method of Sabbagh. The average duration of sunstroke is 9.594 (h), the maximum duration of day of sunstroke is 11.199 (h), the relative humidity is 20.37%, the maximum temperature for the site is 35.65 °C, the rate of sunstroke is 0.857 and the total radiation is 6.013 kWh/m^2/ day.

According to the results obtained by the two models for the site of Faya-Largeau in the Saharan zone of Chad, we note that the value of the total radiation is 5.457 kWh/m^2/day by using the method of Angstrom.

On the other hand, the method of Sabbagh gives a result of 6.013 kWh/m^2/day which approaches more the value of the NASA (6.440 kwh/m^2/day), considered as experimental and reference value. Moreover, this method of Sabbagh has more of the weather parameters than the method of Angstrom. The use of the climatic data has as an advantage a real estimate during a good number of years.

The results of the indicators of precision RMSE, NSE, MBE, and MPE are given in **Table 4** for the site of Faya-Largeau and for the two used methods.

The comparison between the results of the two used methods and the measured values (NASA) shows that the method of Sabbagh gives the best estimation of the total radiation for this zone. It is noticed that the model of Sabbagh gives a minimal variation (MPE(%)= -6.7662%, RMSE= 0.513, MBE=- 0.0677, NSE=0.6468).

Table 4: Comparison of the methods for the site of Faya-Largeau

Indicators of precision	MPE (%)	RMSE (kWh/m^2/day)	MBE (kWh/m^2/day)	NSE (kWh/m^2/day)
Methods				
Angstrom	-13.791	1.289	-0.1379	-1.2293
Sabbagh	-6.7662	0.513	-0.0677	0.6468
Allen	-16.724	1.297	-0.1672	-1.256

Table 5: Monthly variations of the error produced by different models

Month	Angstrom Err(%)	Allen Err(%)	Sabbagh Err(%)
January	4.981	-4.696	-14.049
February	-10.066	-13.944	-14.802
March	-16.757	-17.934	-11.840
April	-23.745	-21.456	-5.409
May	-25.766	-24.973	-5.040
June	-27.056	-26.260	-4.164
July	-23.684	-22.859	-7.781
August	-23.314	-21.857	-9.331
September	-18.124	-21.876	-1.256
October	-11.506	-16.619	0.865
November	-1.523	-9.839	-3.638
December	11.066	1.630	-4.748
Average	-13.791	-16.724	-6.766

Table 5 respectively shows the monthly variations of the errors obtained starting from the various models in particular the method of Angstrom, Allen and Sabbagh. One notices in this table that the model of Sabbagh presents a minimal error of -6.766 % compared to the other models. What comes down to saying that this model is adapted the most to consider the irradiation solar total of Faya-Largeau.

Table 6: Monthly fraction of possible duration of sunshine hours (S/S_0) and the clearness index (H/Ho)

Month	S/So	H/H_o(Angstrom)	H/H_o(Allen)	H/H_o(Sabbagh)
January	0.905	0.673	0.611	0.551
February	0.932	0.672	0.643	0.636
March	0.874	0.672	0.663	0.712
April	0.879	0.673	0.693	0.834
May	0.896	0.673	0.68	0.861
June	0.892	0.673	0.68	0.884
July	0.731	0.654	0.661	0.79
August	0.646	0.629	0.641	0.743
September	0.773	0.662	0.632	0.798
October	0.902	0.673	0.634	0.767
November	0.93	0.672	0.615	0.658
December	0.92	0.672	0.615	0.577
Average	0.857	0.666	0.647	0.734

Table 6 presents the variations of the rate of the sunshine duration S/S_0 , the index of clearness H/H_0 obtained by the three methods used within the framework of this study. It is noticed that, the maximum value of S/S_0 of 0.932 is recorded in February and the minimal value 0.646 in August.

The average value of the index of clearness of these three methods presented in **Table 6** shows that, plus the index of clearness is high, plus the model is better. Thus, the model of Sabbagh is appropriate for the site of Faya-Largeau, with a value of 0.734.

6. CONCLUSION

In this work, a modeling of the Global solar irradiation for the site of Faya-Largeau by the models of Angstrom and Sabbagh has been presented. The performance of two numerical methods has been systematically compared.

This work enabled us to confront the values of the NASA and those estimated by the two mathematical models. According to the results of this study, we noted that the Sabbagh method is very suitable and efficient in order to estimate of the global solar radiation with a value of 6.013 kWh/m^2/day.

The evolution of the monthly solar radiation for the site of Faya-Largeau shows that December and January are the most unfavorable (4.521 kWh/m^2/day and 4.734 kWh/m^2/day respectively).In prospects, one can plan to use this step, improved better to evaluate the solar potential for other sites in Saharan zone of Chad in order to establish the map of the solar potential.

NOMENCLATURE

$H_{i,c}$,$H_{i,m}$	ith calculated and measured	NASA	National Aeronautic and Space
S_o	maximum duration of day of sunstroke		Administration values of H(kwh/m^2/day)
h	height (km)	S	Average monthly value of sunstroke
I_{sc}	Solar constant (equal to 1367 w/m^2)	D_n	current date as from January 1
L	latitude of the place in degrees	RMSE	Root Mean Square Error
S/S_o	the sunshine duration	MBE	Mean Bias Error
H/H_o	index of clearness	MPE	Mean Percentage Error
H	monthly mean daily global radiation on	K	Factor dependent on latitude and the
	horizontal surface (kwh/m^2)		altitude of the site
ψ_{ij}	climatic factor	T_{max}	Monthly mean maximum temperature (°c)
NSE	Nash-Sutcliffe Equation	T_m	Monthly mean minimum temperature (°c)
H_o	Monthly mean daily extraterrestrial		

REFERENCES

[1] H.D. Kambezidis, B.E. Psiloglou, D. Karagiannis, U.C. Dumka and D.G. Kaskaoutis, '*Recent Improvements of the Meteorological Radiation Model for Solar Irradiance Estimates under All-Sky Conditions*', Renewable Energy, Vol. 93, N°C, pp. 142 - 158, 2016.

[2] M. Wild, '*Global Dimming and Brightening: A Review*', Journal of Geophysical Research, Vol. 114, N°D10, 27 May 2009.

[3] R.J. Longman, T.W. Giambelluca and M.A. Nullet, '*Use of a Clear-Day Solar Radiation Model to Homogenize Solar Radiation Measurements in Hawai'i*', Solar Energy, Vol. 91, pp. 102 - 110, 2013.

[4] N.L.A. Chan, T.B. Young, H.E. Brindley, N.J. Ekins-Daukes, K. Araki, Y. Kemmoku and M. Yamaguchi, '*Validation of Energy Prediction Method for a Concentrator Photovoltaic Module in Toyohashi Japan*', Progress In Photovoltaic's: Research and Applications, Vol. 21, N°8, pp. 1598 - 1610, 2013.

[5] B.E. Psiloglou and H.D. Kambezidis, '*Performance of the Meteorological Radiation Model during the Solar Eclipse of 29 March 2006*', Atmospheric Chemistry and Physics, Vol. 7, N°23, pp. 6047 - 6059, 2007.

[6] F. Wang, Z. Zhen, Z. Mi, H. Sun, S. Su and G. Yang, '*Solar Irradiance Feature Extraction and Support Vector Machines Based Weather Status Pattern Recognition Model for Short-Term Photovoltaic Power Forecasting*', Energy and Buildings, Vol. 86, pp. 427 - 438, 2015.

[7] F. Yettou, A. Malek, M. Haddadi et A. Gama, '*Etude Comparative de Deux Modèles de Calcul du Rayonnement Solaire par Ciel Clair en Algérie*', Revue des Energies Renouvelables, Vol. 12, N°2, pp. 331 – 346, 2009..

[8] J.P. M'Batna, '*Energies Renouvelables: Quelles Perspectives pour le Tchad*', Forum Francophonie de l'Innovation, Namur, Fédération Wallonie-Bruxelles, 2014.

[9] M.S. Kaltiya, M.S. Abubakar and I.N. Itodo, '*Prediction of Global Solar Radiation Using Angstrom-Page Equation Model for Makurdi Benue State: Nigeria*', American Journal of Engineering Research, Vol. 3, N°8, pp. 145 - 150, 2014.

[10] F. Ayangma, G.E. Nkeng, D.B. Bonoma and J. Nganhou, '*Evaluation du Potentiel en Energie Solaire au Cameroun : Cas du Nord Cameroun*', African Journal of science and Technology, Vol. 9, pp. 32 - 40, 2008.

[11] C. Augustine and M.N. Nnabuchi, '*Analysis of some Meteorological Data for some Selected Cities in the Eastern and Southern Zone of Nigeria*', African Journal of Environmental Science and Technology, Vol. 4, N°2, pp. 092 - 099, 2010.

[12] N.N. Gana and D.O. Akpootu, '*Angstrom Type Empirical Correlation for Estimating Global Solar Radiation in North-Eastern Nigeria*', The International Journal of Engineering and Science, Vol. 2, N°1, pp. 58 - 78, 2013.

[13] B. Musa, U. Zangina and M. Aminu, '*Estimation of Global Solar Radiation In Maiduguri, Nigeria Using Angstrom Model*', ARPN, Journal of Engineering and Applied Sciences, Vol. 7, N°12, pp. 1623 - 1627, 2012.

[14] A.H. Wereme, '*Contribution à la Mise au Point d'un Modèle de Calcul des Composantes Spectrales du Rayonnement Solaire au Sol dans les Conditions d'une Atmosphère de Brume Sèche en Afrique Sahélienne*', Thèse, Université Cheikh Antadiop de Dakar, 2001

[15] R.G.A. Allen, '*Self Calibrating Method for Estimating Solar Radiation from Air Temperature*', Journal of. Hydrologic Engineering, Vol. 2, N°2, pp. 56 - 57, 1997.

[16] A.K. Katiyar and C.K. Pandey, '*A Review of Solar Radiation Models-Part1*', Hindawi Publishing Corporation Journal of Renewable Energy, 2013.

[17] P.J. Lunde, '*Solar Thermal Engineering: Space Heating and Hot Water Systems*', Wiley, New York, NY, USA,1979.

[18] K. Kerkouche, F. Cherfa, A. Hadj Arab, S. Bouchakour et K. Bergheul, '*Evaluation de l'Irradiation Solaire Globale sur une Surface Inclinée selon Différents Modèles pour le Site de Bouzaréah*', Revue des Energies Renouvelables, Vol. 16, N°2, pp. 2269 - 2284, 2013.

[19] C.K. Panday and A.K. Katiyar, '*Temperature Base Correlation for the Estimation of Global Solar Radiation on Horizontal Surface*', International Journal of Energy and Environment, Vol. 1, N°4, pp. 737 - 744, 2010.

[20] J. Glover and J.S. McCulloch, '*The Empirical Relation Between Solar Radiation and Hours of Sunshine*', Journal of Royal Meteorological Society, Vol. 84, pp. 172 - 175, 1958

[21] S.M. Robaa, '*Evaluation of sunshine duration from cloud data in Egypt*', Energy, Vol. 33, N°5, pp. 785 - 795, 2008.

[22] R. Chen, K. Ersi, J. Yang, S. Lu and W. Zhao, '*Validation of five global radiation models with measured daily data in China*', Energy Conversion and Management, Vol. 45, pp. 1759 - 17, 2004.

[23] Y. Allanaissem, '*Les politiques publiques d'aménagement du territoire dans une dynamique de gouvernance décentralisée du système de développement territoriale durable au Tchad*', Mémoire de Master, 2013.