Available online www.jsaer.com

***Journal of Scientific and Engineering Research*, 2020, 7(4):183-190**

Research Article

ISSN: 2394-2630
CODEN(USA): JSERBR

Estimation of the Swelling Pressure of the Clayey Soils of the TCHI Depression in Benin for the Good Holding of the Equipment's

Koffi Judicaël. AGBELELE[1,2], Abalo P' KLA[3], Kocouvi Agapi Houanou[2], Kebir. Sanny DARA[2], Gérard DEGAN[1,2], Gérard GBAGUIDI AÏSSE[2]

[1]Université Nationale des Sciences Technologie Ingénierie et de Mathématiques (UNSTIM), Abomey, Bénin
[2]Laboratoire d'Energétique et de Mécanique Appliquées (LEMA), EPAC, UAC, 01BP2009 Cotonou, Bénin
[3]École Nationale Supérieure d'Ingénieurs (ENSI) de l'Université de Lomé (UL), BP 1515 Lomé, Togo

Abstract The shrinkage-swelling phenomena of clayey soils as a function of the variation in water content and are manifested by disorders affecting mainly individual houses that are often not very rigid and superficially founded. The superficial foundations of infrastructures built on swelling soils are subjected to several stresses due to shrinkage and swelling phenomena. These stresses are the cause of damage to the structures in the form of cracks, or even lead to the partial or total breakage of the structure when it is built without special precautions. In order to control these induced stresses and safeguard these infrastructures, it is necessary to assess the inflation pressure so that the loads induced by the building are higher than the said inflation pressure produced by swelling clay soils. The objective of this study is to develop a model for predicting the swelling pressure thanks to the physical parameters obtained by laboratory tests on the soils that are the subject of our study.

In order to achieve this goal, we performed several physical and mechanical tests on samples of swelling soils taken from the study area and used the results of these tests to develop a non-linear least squares method for the prediction of swelling pressure models. The models were based on test results from 24 soil samples. The tests were carried out in accordance with the French NF standards. The statistical tests verify the accuracy of the models developed.

This study showed that the swelling of a soil is a function of several physical parameters such as moisture content, liquid limit and dry density. We obtained the model log σg= 3.948 + 0.00031WL -0.1394γd0- 0.0211W allowing us to predict the swelling pressure for the study area. This model is obtained with an accuracy of the regression coefficient r^2 = 99.50%.

Keywords foundations, early degradations, swelling pressure, prediction model

1. Introduction

The question of infrastructure (buildings, surface foundations, retaining structures, embankments, etc.) is of prime importance for any economy. Whatever the type of infrastructure, sub-Saharan Africa and Benin, all the more so, is the victim of under-equipment. When these infrastructures are built on swelling clay soils, they are subject to very early degradation which makes them unusable. The damage caused by this phenomenon is very costly and can be found all over the world [1-2]. In the United States, for example, it has been estimated at 1000 million dollars, and in the United Kingdom at 150 million dollars [3]. It is therefore easy to conceive of the risk of insecurity for the infrastructure erected in these regions where swelling clay soils are found.

The phenomena of shrinkage and swelling of the clayey surface formations thus cause settling and uplifting which manifests itself by the appearance of disorders [4], such as cracks, mainly affecting structures such as individual houses, or social buildings (schools, etc.) built at shallow depths and without special precautions. The examples of disorders linked to the presence of swelling clays are numerous and varied [5-7]. In Benin, these soils are found in the Lama region [5].

One approach to anhydrous shrinkage and swelling is to control the swelling pressure of these clay soils. Knowledge of this swelling parameter can be obtained through mechanical characterization tests in the laboratory and predictive models based on the results of physical characterization tests, which are easier to perform. Prediction of the swelling potential of soils is possible through certain empirical methods based on identification parameters such as plasticity and granulometry determined during physical tests [8]. Einstein [9] thus distinguishes between empirical models, models based on swelling laws, rheological models, models derived from rheological models and hydromechanical models. Several authors have studied the different correlations between the physical and mechanical parameters of clay soils. Most of the models developed have shown their limitations if the soil study area changes.

Thus, A. Djedid et al [10] showed, in their study "Identification and forecasting of the swelling of some soils in the region of Tlemcen (Algeria)", that the forecasting models are sensitive and are only applicable to the soils that were used for their establishment. In the same vein and thanks to a comparative analysis between their models for predicting the swelling pressure and the existing models Anand J.Puppala et al [11] have shown that the models depend on the data employed.

The objective of the present study is to develop a model for the prediction of the swelling pressure thanks to the physical parameters obtained by laboratory tests on the soils subject of our study area, the western part (TCHI depression) of the Lama depression, in BENIN. For this purpose, soil samples were taken in the said depression and allowed us to highlight the variations of the swelling pressure according to the depth and the physical and mechanical nature of the soil. The models were established on the basis of the test results of 24 soil samples. The statistical tests verified the accuracy of the models developed.

2. Materials and Methods

2.1. Identification of soils

Benin is a sub-Saharan country located in West Africa and has a semi-arid climate. It is subdivided into 12 departments and has 77 communes. Several of these communes, located in the southern median zone, have soils with swelling characteristics. According to Judicaël AGBELELE [12], these soils are estimated at more than 3000 km^2, and are found in the Lama depression, which breaks down into three depressions: Issaba in the East, Khô in the Centre, and Tchi in the West. The western depression is our study area. The present study focuses on the soils of the TCHI depression. This depression crosses five communes namely Lokossa, Lalo, Athieme, Houeyogbe and Bopa. The experimental study was carried out on the soils of a few districts of the communes crossed because of the preponderance of damage due to shrinkage and swelling phenomena and the relatively high sinistrality in these localities.

For a better appreciation of the deformations observed at the level of the soils supporting the infrastructures in the TCHI depression, we first proceeded with the geotechnical analysis of twenty-four (24) samples taken from the sites in our study area at depths of 0.50 m to 1.00 m; 1.00 m to 2.00 m and 2.00 m to 3.00 m with respect to the soil.

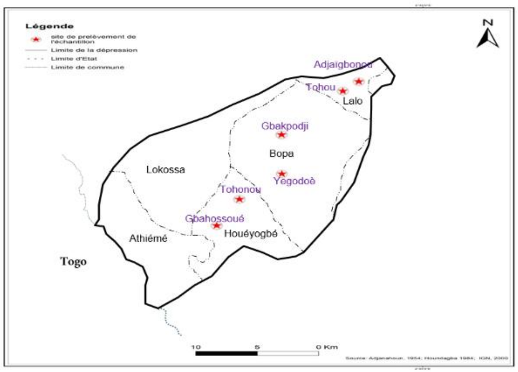

Figure 1: Sample Collection Card

The Centre National des Essais et Recherchesen Travaux Publics (CNERTP) in Benin and the Laboratoire des Travaux Publics (LAB-TP) in Togo served as the framework for carrying out the various tests.

2.2. Methodology for estimating swelling potential

Many authors have worked on the empirical equations in order to be able to determine values of the swelling pressure from conventional and easy to perform tests such as Atterberg limits, shrinkage limits, percentage of clay fraction (< 2 µm) and which provide information on the initial state of the samples such as water content, density and suction. These methods consist of correlating the swelling rate or swelling pressure with some geotechnical identification parameters.

These empirical formulas allow us to determine certain characteristics of swelling soils from the results of identification tests, in order to estimate or quantify the parameters of water and/or mechanical variations.

In our studies, we used a few existing empirical models and adjusted them to apply them to our sites.

From the existing models, we selected a few that are listed below:

- Vijayvergiya and Ghazally [13] propose to determine the logarithm of the inflation pressure by the relation:

$$log\sigma_{g=}\ 0.008WL+1.194\gamma_{d0}-0.183 \text{with,} \quad (1)$$

WL: the liquidity limit of the material

γd0 : the dry density of the material

- Komornik and David [14] developed a model to estimate the inflation pressure by the relationship:

$$log\sigma_{g=}\ -2.132 + 0.0208WL+0.0006064\gamma_{d0}-0.0269W \text{ with,} \quad (2)$$

WL: the liquidity limit of the material

γd0: the dry density of the material

W: the water content of the material

- Nayak and Christensen [15], through their studies, have developed a relationship to obtain the inflation pressure:

$$\sigma_{g=} 0,035817\ \text{IP}^{1.12}\left(\frac{C_2}{W}\right)^2 + 3,7912 \ \text{ with} \quad (3)$$

IP: the plasticity index of the material

C2: Percentage of passes at 2 µm

W: Initial water content

- Choice of prediction model

The reliability of the models listed above will be checked by means of statistical tests, i.e. the Fisher test and the comparison of the R^2 determination coefficients, from the test data obtained per site studied in order to make a choice which will then be contextualized so that it is applicable to our site.

- Definition of the suitability test

Measuring the suitability of a model is based primarily on the calculation of the coefficient of determination (R^2) and residue analysis. The formula used to estimate the coefficient of determination for a non-linear regression is that of Kvalseth [16].

- Parameter identification approach

The parameters of the inflation pressure prediction model were determined by non-linear least squares using the STATA 2014 statistical tool.

By doing so, the coefficients are determined and the model is known. After the model was fitted, statistical tests were carried out to assess the reliability of the fitted model. Among these tests we have: the significance test of the model, the determination of the R^2 coefficient and the analysis of the residuals.

- Meaning of the model

The analysis of the significance of the model will be performed using the Fisher's test at 1% risk. It will confirm the test performed using the r^2 coefficient. In statistics, the test of equality of two variances, is a hypothesis test which allows to test the null hypothesis that two normal laws have the same variance, therefore to verify if the law described by the model has the same variance as the one described by the laboratory test results.

- Coefficient of determination r²

Measuring the suitability of a model is based primarily on the calculation of the coefficient of determination (r²) and residue analysis. According to Kvalseth [16], the appropriate formula for evaluating the coefficient of determination for a non-linear regression is of the form:

$$R^2 = 1 - \frac{SSR}{SSE}, \text{ with} \quad (4)$$

$$SSR = \sum_{i=1}^{n}(y_i - \bar{y})^2 et SSE = \sum_{i=1}^{n}(y_i - \ddot{y}_i)^2 \quad (5)$$

$\ddot{y}_i$: value of the inflation pressure predicted by the model

y_i: Value of the inflation pressure obtained by test

$\bar{y}$: Average inflation pressure values obtained by testing

From this model we moved to its adjustment by numerical approach to identify the parameters.

- Residue analysis

It is an essential part of the adequacy study of any model. The review of residuals will take place in two distinct stages: model validity and model quality. The validity study is based primarily on the statistical test of normality of the residuals.

2.3. Material

The equipment used for the physical and mechanical parameters of the soils in our study area are: a Casagrande apparatus for the determination of Atterberg limits, a set of sieves for the determination of the passageways to the different sieves including the 2 µm sieve, an oven for drying the materials, balances for weighing the samples and an oedometer for the determination of the swelling pressure.

3. Results and Discussion

3.1. Results of Physical and Mechanical Tests

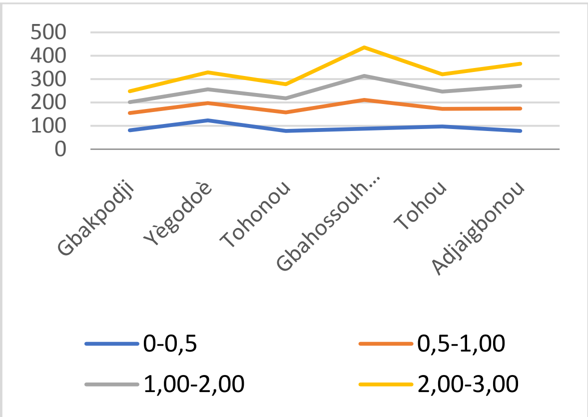

Figure 1 : Liquidity limits of the sites studied by depth

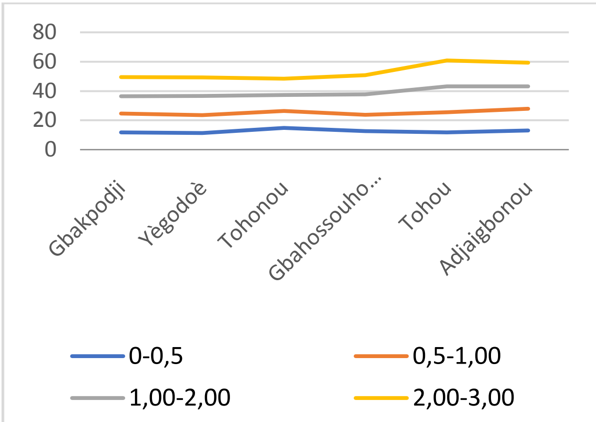

Figure 2: Densités sèches des sites étudiés par profondeurs

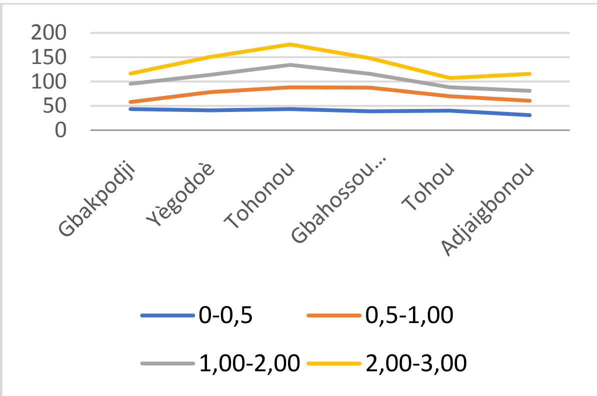

Figure 3: Water content of the sites studied by depths

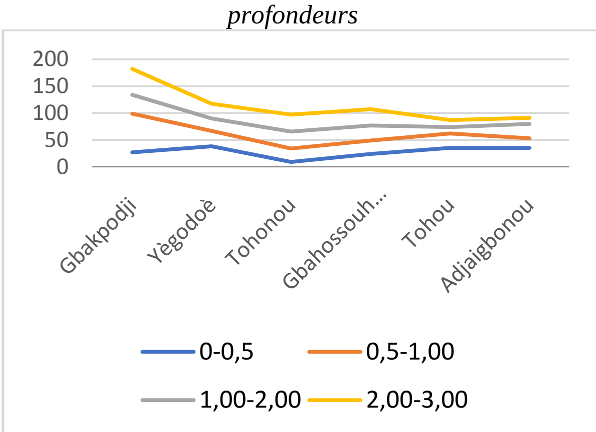

Figure 4: Swelling pressure of the sites studied by depths

These graphs present the results of soil sample identification tests for the study sites in the TCHI depression.
We can deduce on the basis of Snethen's [17] classification, which uses the plasticity index to determine the swelling potential, that our soils have a swelling potential that ranges from medium to very high. The other parameters, namely activity, water content, swelling pressure and specific weight, allowed us to confirm that we are in the presence of a swelling soil.

3.2. Choice of prediction model

The choice of the prediction model was guided by various statistical tests including the Fisher Test and the r^2 coefficient of determination. The tests were carried out for the different existing models.
For each of the sites studied in the TCHI depression and for all depths, the results of the Fisher's test and the model regression coefficient are as follows:

Table 1: Results of the Fisher tests and the r^2 coefficient

Depressions	Models	Coefficient r^2	Test of Fisher
TCHI	*Vijayvergiya et Ghazally*	0.4333	The model does not fit the data correctly.
	Komornik et David	0.4634	
	Nayak et Christensen	0.4479	

The above results indicate that none of the models fit the data correctly and therefore cannot be used to predict the inflation pressure of the study sites. It will therefore be necessary to establish a prediction model appropriate to the sites studied.
Although all three models based on Fisher's test do not fit the data correctly for all study sites, the model by Komornik and David [14] has a better calculated r^2 coefficient of determination. Thus, in our research, we will fit this model.
Thus, the expression of the model to be fitted is :

$$d + aWL + b + cW; \quad (6)$$

with a, b, c and d model parameters.

3.3. Determination of model parameters

The adjustment of the function $log\sigma_g\left(WL, \gamma_{d0}, W\right)$. was done by the non-linear least squares method. Table 2 below summarizes the values of the parameters found:

$$log\sigma_{g_j} = \Sigma_{j=1}^{n}(y_j - log\sigma_g\,(WL, \gamma_{d0}, W))^2 \quad (7)$$

Table 2: Coefficients a, b, c, and d determined using the least squares method

Depression	Depths (m)	a	b	c	d
TCHI	0.00 – 0.50	0.000652	-0.1486	-0.024	4.139
	0.50 – 1.00	0.000328	-0.1424	-0.022	4.000
	1.00 – 2.00	0.00039	-0.161	-0.0244	4.334
	2.00 – 3.00	0.00056	-0.128	-0.0193	3.722

The different parameters a, b, c, and d allowed us to write the different models for predicting the inflation pressure.

3.4. Standardization of established models

The analysis of the different models established led us to look for similarities between the different models in order to determine a single model for depression at any depth. To this end, we have :
- established a single model for the depression from 0.50 m to 3.00 m in depth (the 0.00 m to 0.50 m range was not taken into account because generally the anchorage depth for any structure is at least greater than 0.50 m);
- verified the adequacy of the unified models established ;
- assessed the effectiveness (accuracy) of the different unified models established for the different depths (at intervals).

3.5. Determination of unified models

The determination of the unified models was done in the same way as the interval models. The values of parameters a, b, c and d of the Komornik and David [14] model at any depth are summarized in the following table :

Table 3: Coefficients a, b, c and d from established models based on the Larson Rolf model

Depression	Depths (m)	a	b	c	d
TCHI	0.50 – 3.00m	0.0003125	-0.13944	-0.02109	3.948

These coefficients allowed us to rewrite the fitted models and then conduct fit testing.

Significance test of each model

The following table presents the result of the Fisher test.

Table 4: Result of the Fisher test of unified models.

Depths (m)	Depression	Fcalc	FRead
0.50-3.00	TCHI	861.89	26.98

Statistical tests show that for all sites and regardless of the model, Fcal is superior to Flu, according to Montgomery and Runger (2003)[18]. We can conclude that the different numerical models developed fit the experimental data well.

- Residue Normality

Table 5: Residue normality test results on unified models

Depths	Depression TCHI		
	σgPrédict	σg Laboratory	Error (ei)
0.50-1.00 m	71.45	72	0.55
	29.17	29	0.17
	26.02	25	1.02
	25.18	25	0.18
	26.49	27.13	0.64
	18.5	17.8	0.7
1.00-2.00 m	34.24	35	0.76
	24.58	23	1.58
	30.44	31.4	0.96
	28.62	28	0.62
	13.44	12	1.44
	49.73	48	1.73
2.00-3.00 m	26.34	27	0.66
	32.63	31.6	1.03
	29.16	30.1	0.94
	12.17	12.89	0.72
	26.94	27.13	0.19
	9.56	11	1.44

Looking at the previous table, we see that none of the residues are outside the range [2; -2]. We can assume, according to Montgomery and Runger [18], that the estimated residuals (errors) are normally distributed. The following table presents the results of the adequacy tests carried out:

Table 6: Residual normality test result for unified models

Tests Depressions	Coefficient r^2	Fisher's suitability test	Outliers searches	Normality of errors
TCHI	0,9950	Ajustcorrectelydata	N/A	OK

In order to better appreciate the quality of the different models, the following curves have been established and allowed to observe the discrepancies between the laboratory data, the fitted and non-fitted model.

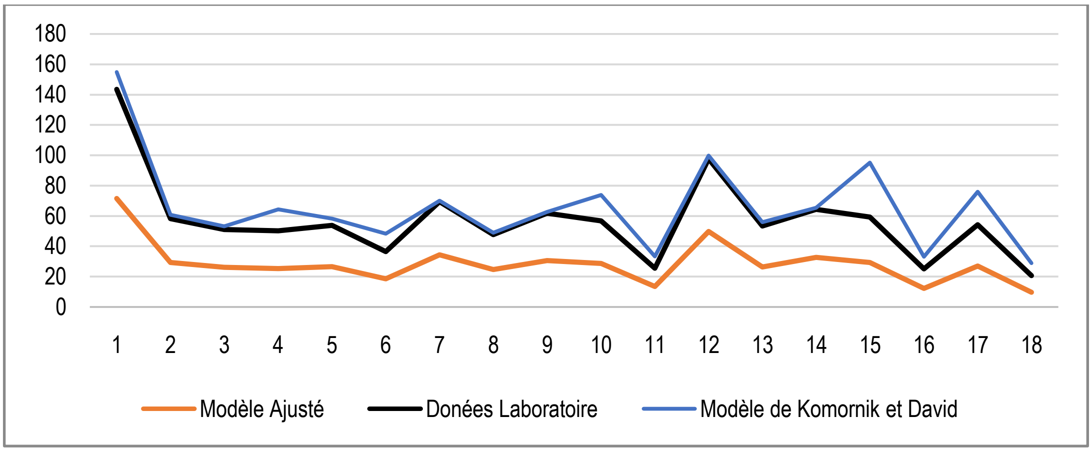

Figure 5: Evolution of the inflation pressure as a function of the sites of the TCHI depression

We can see that the curves "Fitted Model" 3.948 + 0.00031WL -0.1394 - 0.0211W and that of the "Laboratory Data" fit together with a few differences. What justifies then the precision of the model close to 99% and moves away very well from the model of Komornik and David [14].

Verification of the effectiveness of the unified models for different depths

To check the accuracy of the different models, the regression coefficient was determined for each model with interval data. With a regression rate greater than 95% according to Montgomery and Runger [18], the model is considered viable for the selected interval.

Table 7: Reliability test results for models unified by depths

Depths	Dépressions	Coefficient r^2	Test de Fisher
0.50-1.00	TCHI	0.9938	The model correctly adjusts the data
1.00-2.00	TCHI	0.9923	The model correctly adjusts the data
2.00-3.00	TCHI	0.9745	The model correctly adjusts the data

Through this table, we notice that the r^2 coefficient is higher than 95% (0.95) for all depths. The unified models therefore fit the studied data perfectly and can be used to determine the inflation pressure for depths from 0.50 m to 3.00 m for the sites studied without having to resort to various expensive tests.

4. Conclusion

In the Lama Trough, particularly the TCHI Trough, experimental study of intact soils collected at various depths concluded that these soils are clays and that correlations can be established. The study of the modelling of the swelling pressure is of paramount importance. It has identified models for predicting swelling pressure as a function of physical parameters. The unified model, based on the model of Komornik and David (1969)[14], can be used to predict the inflation pressure of the soils of the localities studied in the TCHI Depression. This model will make it possible to predict one of the stresses induced by these soils on the foundations erected there and others by helping to safeguard and ensure the good performance of the structures built in these risk areas.

References

[1]. Masoumeh Mokhtari, Masoud Dehghani, “Swell-Shrink Behavior of Expansive Soils, Damage and Control” EJGE Vol. 17 [2012], Bund. R

[2]. Jones, Lee D.; Jefferson, Ian. 2012 Expansive soils. In: Burland, J., (ed.) ICE manual of geotechnical engineering. Volume 1, geotechnical engineering principles, problematic soils and site investigation. London, UK, ICE Publishing, 413-441.

[3]. Gourley C.S., Newill D. and Schreiner H.D. (1993) Expansive soils: TRL's research strategy. The First International Symposium on Engineering Characteristics of Arid Soils, p.247-261.

[4]. A. El Yaakoubi1, A. Asselman1, H. Asselman1 And S. Ahyoud1, New empirical model of free swelling clay soils, MATEC Web of Conferences, 11,02011 (2014), DOI: 10.1051/matecconf /20141102011.

[5]. V. GBAGUIDI et al, Etude du phénomène de gonflement des sols argileux du bassin sédimentaire côtier au Bénin, (2010).
[6]. Yvette S. T. KIKI, (2004) - Contribution à la mise au point de Méthodes de stabilisation des sols Gonflants : application aux sols argileux de la lama (Onigbolo, Bénin). Thèse de doctorat de 3ème cycle de l'Ecole Supérieure Polytechnique de THIES.
[7]. Kirsten Hendriks, (2008) - Etude et analyse des sols gonflants au Bénin. Thèse de doctorat, EPAC et Université de liège.
[8]. Amal Medjnoun, Mohamed Khiatine&Ramdane Bahar, « Caractérisation minéralogique et géotechnique des argiles marneuses gonflantes de la région de Médéa, Algérie » Bulletin of Engineering Geology and the Environment volume 73, pages1259–1272(2014)
[9]. Einstein, H.H., and Bischoff, N. (1976). Dimensionnement de tunnels en roche gonflante. (Design of tunnels in swelling rock.) Tunnels et Ouvrages Souterrains.
[10]. A. Djedid, A. Bekkouche, S.M. Aissa Mamoune « Identification et prévision du gonflement de quelques sols de la région de Tlemcen (Algérie) » Bulletin de liaison des Laboratoires des Ponts et Chaussées, 2001, vol. 233, pp. 67-75.
[11]. Anand J. Puppala Thammanoon Manosuthikij And Bhaskar C.S. Chittoori, Swell and shrinkage strain prediction models for expansive clays, Engineering Geology Volume 168, 16 January 2014, Pages 1-8, DOI: 10.1016/j.enggeo.2013.10.017
[12]. Koffi Judicaël Agbélélé, Gérard GBAGUIDI AÏSSE, Abalo P'KLA et Gérard DEGAN (2016) « Caractérisation physico-mécanique des sols argileux de la dépression d'Issaba au Sud-Est du Bénin ». Afrique sciences vol. 12, N°2.
[13]. Vijayvergiya et Ghazally (1973). Prediction of swelling potential for natural clays, proceedings, 3rd International Conference on Expansive Soils. Jerusalem, Academic Press, vol. 1, pp.227-236.
[14]. Komornik A. & David D A. (1969) - Prediction of swelling potential for compacted clays, ASCE, Journal of the Soil Mechanics and Foundation Division, vol. 95, n° 1, pp. 209-225.
[15]. Natasha V. Nayak, Roy Walter Christensen Swelling Characteristics of Compacted, Expansive Soils, Clays and Clay Minerals 1971 Vol. 19 pp. 251-261. Pergamon Press. Printed in Great Britain.
[16]. Kvalseth T.O. (1985): « Cautionary note about r^2 », The American Statistician, Vol 39, pp2.79-85.
[17]. Snethen D. R., Characterisation of expansive soils using soil suction data. Proceeding 4th I.C.E.S. Denver, p.54-75 (1980).
[18]. Montgomery D.C., Runger G.C., 2003. Applied Statistics and Probability for Engineers, Third edition. John Wiley and Sons, Inc. Arizona State University.