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Influence of the Lithostabilization of A Swelling Clay on its Plasticity and its CBR: the Case of Dabanga Karal Coupled with the Sand of Mayo Kaliao River in the Far North Region of Cameroon

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Abstract —**This article aims, from certain geotechnical characteristics of Dabanga Karal, to carry out tests to improve its plasticity and its CBR bearing capacity by litho-stabilizing it with sand taken from the Mayo Kaliao River in Maroua, situated in the Far North Region of Cameroon, following mixtures weights of 10, 15, 20, 25 and 30% sand. The work done is essentially experimental through tests carried out at the National Civil Engineering Laboratory (LABOGENIE) in Yaoundé, according to the relevant French standards. The results obtained show that after lithostabilization of Dabanga Karal with the sand of Mayo Kaliao River, the plasticity index and the linear swelling drop respectively while the CBR increases significantly. These results are compared with CEBTP specifications ([3] &[4] relating to the dimensioning of low traffic roads in tropical areas. This research work made it possible to show that the Karal, although being a swelling clay with high plasticity, presents after lithostabilization a plasticity and a CBR which can allow its use in platform, in the construction or the maintenance of roads in the northern part of Cameroon, in accordance with CEBTP specifications.**

Keywords: Karal; Dabanga; swelling clay; plasticity; CBR; lithostabilization.

1. INTRODUCTION

The Karal is an abundant clay soil in the northern part of Cameroon, more precisely in the Far North Region where it covers about 73% of the soil [5]; to cope with the absence of lateritic materials in this Region, this clay is frequently used both in the construction of paved roads (in a platform or subgrade) and in the development and maintenance of roads in earth (as soil in place or in embankments). The Karal, resistant in the dry season, is very plastic and swells in the presence of water due to the presence of swelling clay minerals such as montmorillonite, kaolinite or illite [2] & [7]. This phenomenon of shrinkage-swelling of this clay and its high plasticity thus make dirt roads impassable during the rainy seasons due to sloughs and paved roads subject to significant degradation.

Indeed, with a Liquidity Limit WL = 62.88% and a Plasticity Index IP = 39.58%, Karal de Dabanga is classified, in the plasticity chart of Casagrande among the mineral clays of high plasticity [9].

The Karal of Dabanga, like most of the soils of the Far North Region of Cameroon, has a very heterogeneous character ([5], [6] & [8]) which requires that, for specific studies in a given area, the characterization should be done beforehand. The lithostabilization of the Karal can be an asset in improving its geotechnical characteristics with a view to its use in the construction of roads in the aforementioned region.

The general objective of this article is to make a contribution to the good behavior of the roads in the northern part of Cameroon, through the improvement of certain geotechnical characteristics of Dabanga Karal, used as material for the construction and maintenance of roads. More specifically, it will be a question of showing how plasticity and CBR lift are influenced by lithostabilizing Dabanga Karal with a granular material, in this case the sand of Mayo Kaliao River in Maroua. The CEBTP specifications ([3] & [4]) relating to the dimensioning of low-traffic roads in tropical areas are used to check the conformity of the results obtained on the Karal-Sand mixtures with a view to their possible use in a platform or in foundation layers. of a roadway.

The work is carried out through tests carried out at the National Civil Engineering Laboratory (LABOGENIE), in particular with regard to the determination of the Atterberg limits and the CBR after immersion, in accordance with the relevant French standards (NF P 94-051 and NF P 94-078). For this, five Karal samples were taken in Dabanga, a locality located 190 km from

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the city of Maroua on the Maroua-Kousseri axis; a sample of sand was also taken from the Mayo Kaliao, a River that meanders through the town of Maroua.

2. THE CAMEROONIAN KARAL

Karal is a more or less dark gray clay that soil scientists call tropical black clay and found in the northern part of Cameroon. Most of the Cameroonian Karal is found in the Far North Region where Ekodek [5] places it between the 14th and 16th degree of longitude East, then the 10th and 13th of latitude North; he estimates the area occupied by the Karal at approximately 25,000 km^2, or nearly 73% of the soils of this Region.

The Karal, made up of a mixture of montmorillonite, kaolinite, illite and a few other minerals, is presented as a material whose ability to shrink-swell would be linked to the quantity of montmorillonite and the importance of the fraction clay (< 2µm) it contains [10].

When a sample of Karal is sieved, it is found that it is essentially made up of fine elements. With a liquidity limit sometimes approaching 70%, the Karal has a plasticity index close to 40% which means that in the rainy season it is practically impossible to travel on a dirt road; Indeed, this clay becomes subject to significant deformations due to traffic, giving rise to deep ruts that make traffic almost impossible [8].

Another characteristic of Karal, a consequence of its high plasticity, is its ability to shrink-swell. In the dry season, the Karal shrinks and cracks that can reach 1 m deep and 4 to 8 cm wide form on the surface [8]. During the rains, these cracks are filled with water which the Karal absorbs and begins to swell.

All these properties make Karal a material whose mechanical characteristics are quite mediocre: [8] & [10] show that a CBR test on Karal soaked at 4 days will rarely give a result higher than 5%.

3. PHYSICAL AND MECHANICAL CHARACTERISTICS OF THE DABANGA KARAL

3.1 Location of the Karal sampling site in Dabanga

Dabanga is a border locality of Cameroon with the Republic of Nigeria, located in the Department of Logone-et-Chari, on the Maroua-Kousseri road, in the Far North Region. It is at a distance of about 190 km from Maroua, 70 km from Kousseri and 1,500 km from Yaoundé, the capital of Cameroon. Geographically, and as shown in Figure 1, Dabanga is located between the 10th and 13th degree of North latitude, then between the 14th and 16th degree of East Longitude ([5] & [6]). A GPS point has been surveyed for a more precise location of the sampling location; its UTM coordinates are as follows: X = 0 461 546 m; Y = 1 317 650 m; Z = 297 m.

Fig. 1. Fig. 1. Geographical location of Dabanga

3.2 Some known results on the characterization of the Dabanga Karal [9]

It appears from the particle size analysis that the clay fraction (< 2µ) contained in the Karal of Dabanga is 61.2%, that of the sands is 24.5% and the silts 14.3%; the percentage of fine elements (passing at 80µ) of the Karal is 81.8%. The other geotechnical characteristics of Karal of Dabanga are recorded in Table 1.

Table 1. Some geotechnical characteristics of Karal de Dabanga [9]

N°	Designation of parameters	Samples results					
		G1	G2	G3	G4	G5	Average
1	Natural water content (%)	18	13	14	13	11	13,80
2	Liquidity Limit (%)	64,1	66,2	62,5	57,6	64,0	62,88
3	Plasticity Limit (%)	26,1	21,3	22	21,1	26,0	23,30

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4	Plasticity Index (%)	38	44,9	40,5	36,5	38,0	39,58
5	Consistency index (%)	1,213	1,185	1,198	1,222	1,395	1,24
6	Linear Swelling (%)	3,8	3,07	4,17	3,15	4,13	3,66
7	Immediate CBR (%)	10,71	7,857	8,571	10,57	10,79	9,70
8	CBR after 4 days of immersion (%)	6,60	4,50	5,00	6,00	6,50	5,72
9	Saturation water content (%)	22,4	17,6	23,5	18,4	22,4	20,86
10	Maximum dry Density (kN/m3)	17,47	17,79	17,59	18,59	17,40	17,77
11	Optimum water content (%)	17,3	15,0	19,0	14,6	17,6	16,7

4. KARAL LITHOSTABILIZATION TESTS PERFORMED (KARAL-SAND MIXTURES KS)

For the realization of the lithostabilisation tests of Karal, (mixtures KS), it is necessary on the one hand, to make combinations in weight of the two materials from where the choice to vary the percentage of sand from 10 to 30% and that of the Karal from 90 to 70%, following in steps of 5%. On the other hand, these combinations apply to each of the five samples from Karal. Hence the matrix of combinations of each test shown in Table 2.

Table 2. Matrix of the combinations of each test

Samples **Combinations (%)**	**G1**	**G2**	**G3**	**G4**	**G5**	**Averages**
90K + 10S	x	x	x	x	x	x
85K + 15S	x	x	x	x	x	x
80K + 20S	x	x	x	x	x	x
75K + 25S	x	x	x	x	x	x
70K + 30S	x	x	x	x	x	x

With :

- 90% Karal + 10% Sand, abbreviated 90K + 10S;
- 85% Karal + 15% Sand, abbreviated 85K + 15S;
- 80% Karal + 20% Sand, abbreviated 80K + 20S;
- 75% Karal + 25% Sand, abbreviated 75K + 25S;
- 70% Karal + 30% Sand, abbreviated 70K + 30S.

Thus, for a given test, each of the five samples is analyzed five times according to the five combinations defined in table 2. The tests described below were carried out on the Karal-Sand (KS) mixtures in the context of this article.

4.1 Atterberg limits, NF P 94-051 standard

The Atterberg limits are geotechnical parameters used to identify a soil and to characterize its state of consistency. The test, which is very important for determining the plasticity of the soil, consists in determining two Atterberg limits: the liquid limit at the cup WL and the plasticity limit of the roller WP for the fraction of soil passing through the 400 µm sieve.

The Atterberg limits are water contents by weight corresponding to particular states of a soil:

- The liquid limit at the cup WL is the water content of a reworked soil at the transition point between the liquid state and the plastic state. Figure 2 illustrates the equipment used in the laboratory for the determination of this limit.

Fig. 2. Equipment for determining the liquid limit in the laboratory

- The WP roller plasticity limit is the water content of a reworked soil at the point of transition between the plastic state and the solid state.

The plasticity index IP, which is the difference between the liquid and plasticity limits, defines the extent of the plastic domain of a soil (IP = WL-WP).

4.2 Immediate and after 4 days of immersion CBR tests, Standard NF P 94-078

The CBR tests was carried out according to the French Standard NF P 94-078 for lithostabilization. The general principle of this tests consists in measuring the forces to be applied to a cylindrical punch with a section of 19.35cm^2 to make it penetrate at constant speed into a specimen of compacted material. The particular values of the two forces which caused two conventional depressions (2.5 and 5 mm) are respectively related to the values of the forces 13.35 and 19.93 kN observed on a reference material for the same depressions.

The desired index called "Californian lift index" is conventionally defined for two states (immediate CBR index and CBR index after immersion) as being the greater value, expressed as a percentage, of the two ratios thus calculated. We then have the desired index ICBR given, according to the energy of compaction (at 10, 25 or 55 blows), by the relation:

$$I_{CBR} = \max \begin{cases} \dfrac{\text{penetration force at 2.5 mm penetration (in kN)}}{13{,}35} \times 100 \\ \dfrac{\text{penetration force at 5.0 mm penetration (in kN)}}{19{,}93} \times 100 \end{cases}$$

The values of the following parameters are normalized: section of the punch, driving speed, conventional driving and forces observed on the material.

In the context of this work, the immediate CBR index, the CBR index after 04 days of immersion and the linear swelling were determined at a compaction water content of 95% of the OPM according to standard NF P 94- 078 Karal-Sand mixtures (KS).

Figure 3 presents a punching session, after 04 days of immersion, of a specimen of the Karal-Sand mixture on the press in the laboratory.

Fig. 3. Punching a CBR specimen in the laboratory

4.3 Linear swelling test conducted concomitantly with the CBR test after immersion, Standard NF P 94-078

The linear swelling g is determined by the relation:

$$g = \left(\frac{h - h_0}{h} \right).100$$

Where h_0 is the height of the specimen before immersion and h the final height after immersion. In practice, the value of the relative elongation $\Delta h = h\text{-}h_0$ of the specimen is determined using a comparator carefully installed on the latter before its immersion as shown in the figure 4.

Fig. 4. Linear swelling measurement device on a CBR mold in the laboratory

5. RESULTS AND DISCUSSION

5.1 Characterization of the sand from Mayo Kaliao River

The Mayo-Kaliao is a river that winds through the town of Maroua and which was selected for the sampling of sand for this study. The sand of this river, like that of other Mayos in the Far North Region, is quite clean, very abundant and accessible during the dry seasons due to the drying up of these rivers.

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Table 3 and Figure 5 present respectively the analysis sheet and the granulometric curve of the Mayo-Kaliao sand.

Table 3. Particle size analysis sheet for the Mayo-Kaliao sand

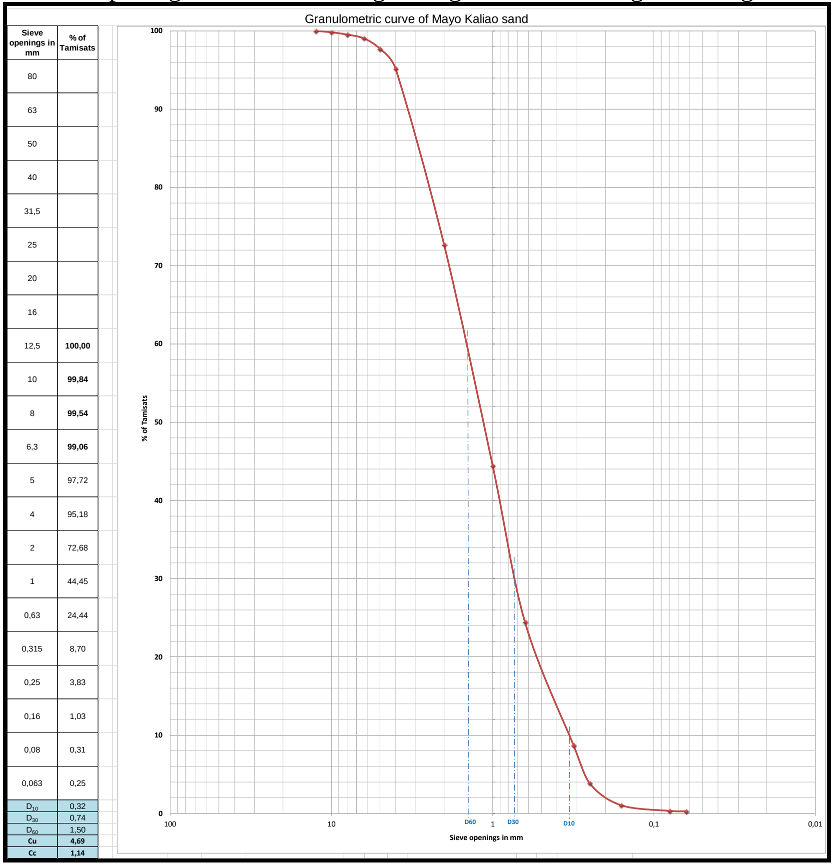
Dry initial weight (grs)		**2000,0**	
Sieve openings (mm)	**Weight of cumulative refusals**	**% Cumulative Refusals**	**% of passers-by**
12,5	0	0,000	100,000
10	3,3	0,165	99,835
8	9,2	0,460	99,540
6,3	18,8	0,940	99,060
5	45,6	2,280	97,720
4	96,4	4,820	95,180
2	546,4	27,320	72,680
1	1111,1	55,555	44,445
0,63	1511,3	75,565	24,435
0,315	1826,0	91,300	8,700
0,25	1923,4	96,170	3,830
0,16	1979,4	98,970	1,030
0,08	1993,9	99,695	0,305
0,063	1997,0	99,850	0,150

The particle size analysis of the Mayo-Kaliao sand shows that this sand is coarse and contains very few fine elements (0.31%). On the other hand, with a uniformity coefficient Cu of 4.69 and a curvature coefficient Cc of 1.13, this sand is a well-graded material (1 < Cc < 3) with a spread granulometry (Cu > 4).

As a reminder, the coefficients of uniformity and curvature are respectively given by the relations below:

$$Cu = \frac{D_{60}}{D_{10}} \quad et \quad Cc = \frac{\left(D_{30}\right)^2}{D_{60}.D_{10}}$$

Where Dx represents the opening of the sieve letting through x% of the weight of the grains.



Sieve openings in mm	% of Tamisats
80	
63	
50	
40	
31,5	
25	
20	
16	
12,5	**100,00**
10	**99,84**
8	**99,54**
6,3	**99,06**
5	97,72
4	95,18
2	72,68
1	44,45
0,63	24,44
0,315	8,70
0,25	3,83
0,16	1,03
0,08	0,31
0,063	0,25
D_{10}	0,32
D_{30}	0,74
D_{60}	1,50
Cu	**4,69**
Cc	**1,14**

Fig. 5. Granulometric curve of the Mayo-Kaliao sand

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5.2 Atterberg limits of KS mixtures

The average values of the Atterberg limits of the five Karal samples litho-stabilized with Mayo Kaliao sand are presented in the table 4.

Table 4. Average values of the Atterberg limits of the lithostabilized Karal with sand

Parameters	Karal-Sand mixtures (KS)					
	100K+0S	90K+10S	85K+15S	80K+20S	75K+25S	70K+30S
Liquidity Limit	62,90	62,76	60,10	58,84	59,12	57,10
Plasticity Limit	23,32	24,98	23,18	24,70	26,28	25,00
Plasticity Index	39,58	37,78	36,92	34,14	32,84	32,10

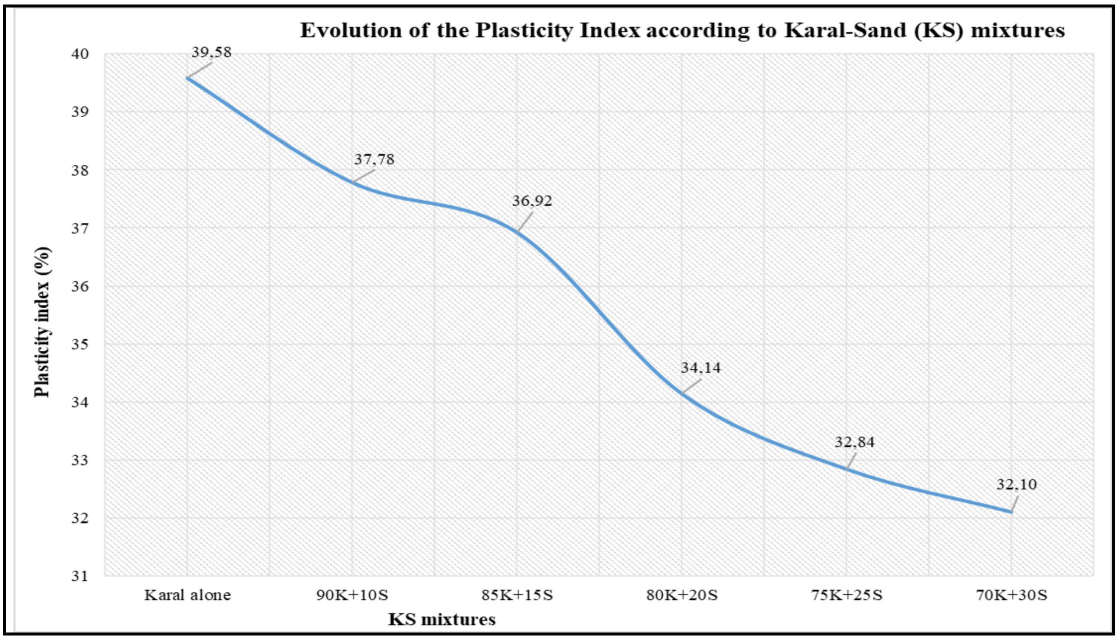

Fig. 6. Evolution of the Plasticity Index of KS mixtures

By comparing the Plasticity indices of the above KS mixtures with that of Karal alone, the evolution curve of this plasticity index can be plotted as shown in Figure 6. Reading this graph shows that the addition of sand in the Karal decreases its plasticity; in fact, the plasticity index goes from 39.58% for the Karal alone to 32.10% for the 70K+30S combination, i.e. a decrease of 7.48%; but this value remains quite high for use in pavement layers according to CEBTP prescriptions.

Moreover, this couple KS can be placed in the Casagrande plasticity chart as shown in figure 7; we can thus see that it remains in the field of mineral clays with high plasticity, but its position is below that of the Karal alone in this abacus.

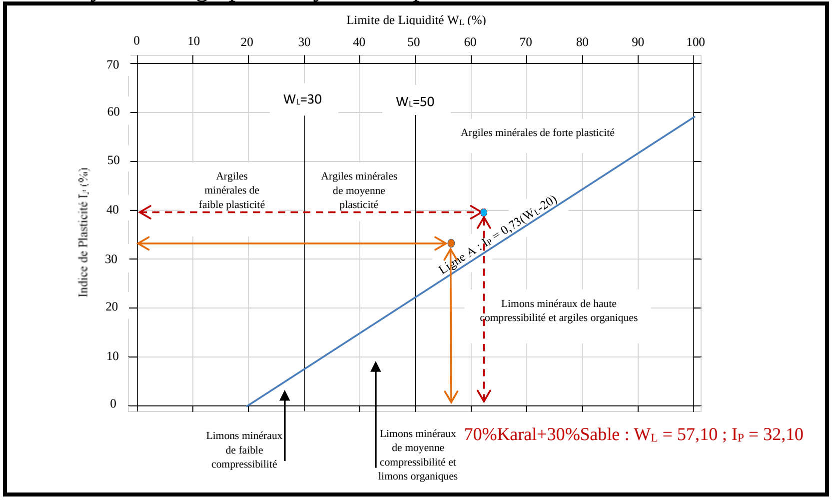

Fig. 7. Position of the couple 70K+30S (orange point) in the Casagrande Plasticity Abacus

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5.3 CBR and Linear Swelling tests of Karal-Sand (KS) mixtures

During these tests, the values of the CBR indices immediately and after 4 days of immersion were determined concomitantly with those of the Linear Swelling of the specimens. These values, which represent the means obtained on the five samples, are presented in table 5.

Table 5. Mean values of CBR and linear swelling of Karal-Sand mixtures (KS)

Parameters	**Mixtures of KS**					
	Karal elone	**90K+10S**	**85K+15S**	**80K+20S**	**75K+25S**	**70K+30S**
Immediat CBR (%)	9,70	11,55	12,73	13,82	14,22	14,95
CBR after immersion (%)	5,72	6,92	8,08	10,20	11,20	12,88
Linear Swelling (%)	3,66	2,98	2,48	2,07	1,86	1,25

Figures 8 and 9 represent respectively the evolution curves of the CBR indices immediately and after immersion at 95% of the OPM and that of the linear swelling of the different combinations of the KS mixture.

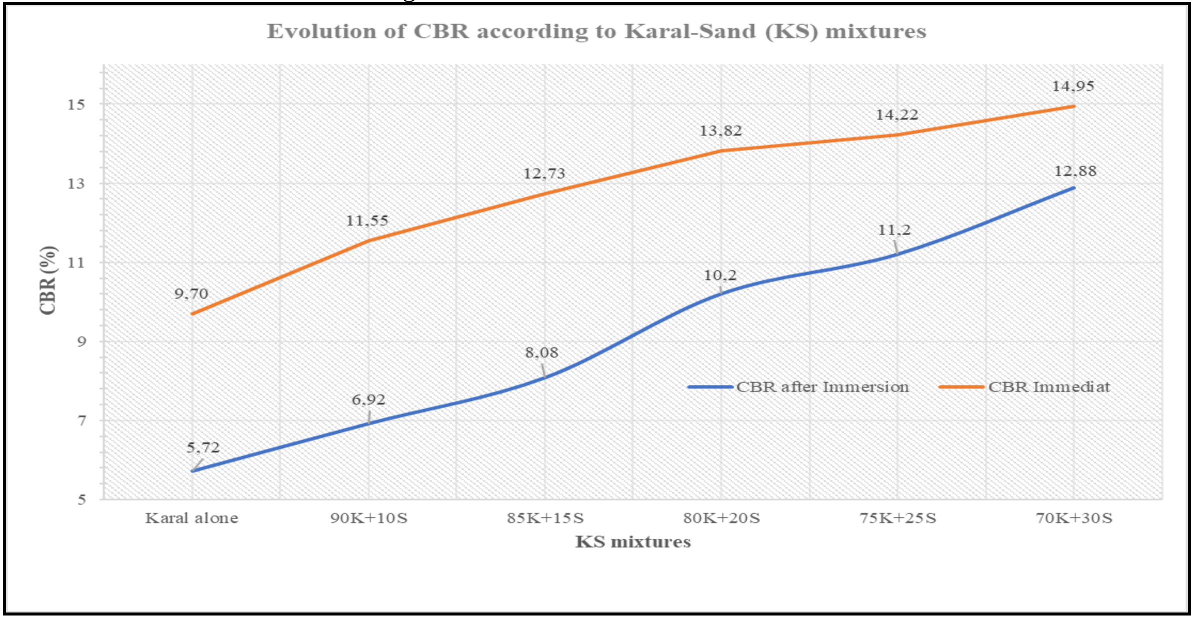

Fig. 8. CBR evolution curves of KS mixtures

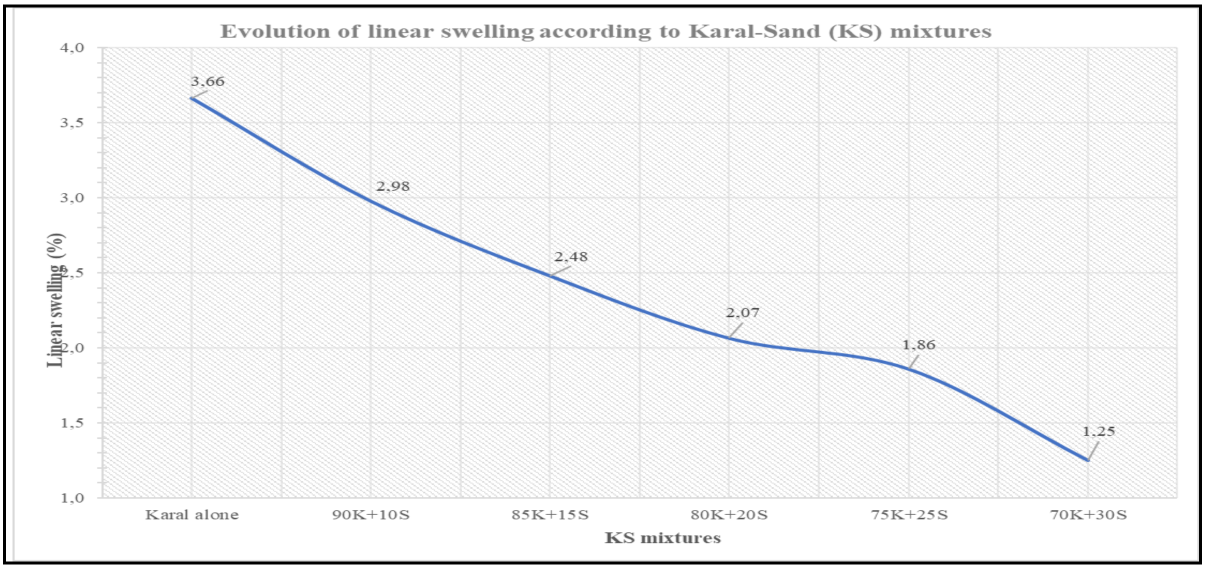

Fig. 9. Evolution curve of linear swelling of KS mixtures

The interpretation of Figure 8 shows that the value of the immediate CBR ranges from 9.70% for the Karal alone to 14.95% for the 70K+30S combination, i.e. an increase of 5.26%; similarly, that of CBR after 4 days of immersion goes from 5.72% for the Karal alone to 12.88% for the 70K+30S combination, i.e. a substantial increase of more than double the value of the Karal alone. On the other hand, figure 9 shows that the linear swelling decreases from the value of 3.66% for the Karal alone to 1.25% for the 70K+30S combination, i.e. a decrease of more than half of the swelling of the Karal only.

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5.4 Discussion

The improvement of the Karal has to date been the subject of a number of works through lithostabilization with sand ([1] & [11]). Table 6 presents the main results obtained by these authors.

Table 6. Comparison of the main results of the lithostabilization studies of the Karal

Parameters	BAANA (2018)		MBESSA & al. (2019)	
	Karal of Maroua	Karal + 30%sand	Karal of Maroua	Karal + 30%sand
Liquidity Limit WL	56,84	*	41,50	*
Plasticity Limit WP	31,64	*	17,31	*
Plasticity Index IP	25,20	*	24,19	*
CBR after immersion	4,30	5,31	*	*
Linear swelling	10,26	4,36	2,35	1,13

It appears that lithostabilization was used by Baana [1] and Mbessa [11] to improve the Karal of Maroua with sand from the Sanaga River, but the two authors did not determine the plasticity of the Karal-Sand mixtures; the CBR lift of the Karal and mixtures was also not determined by Mbessa. The linear swelling of 10.26% found by Baana on the Karal de Maroua is almost 5 times higher than that of 2.35% found by Mbessa; after lithostabilization of 30% sand, these swellings increase to 4.36% and 1.13% respectively. These significant differences can further explain the heterogeneous character of the Karal de Maroua; however, the Plasticity Indices found by these two authors on the Karal alone do not show a significant difference, respectively 25.20% for Baana and 24.19% for Mbessa. In addition, after lithostabilization, Baana finds a very low CBR value of 5.35% which is satisfactory for use in a platform but not in a foundation layer or base layer according to CEBTP specifications.

The lithostabilization of the Karal of Dabanga with the sand of Mayo Kaliao made it possible to show that the geotechnical characteristics of the Karal are improved. Indeed, the Atterberg limits, the CBR after imbibition and the linear swelling are the tests that were carried out on the five samples from Karal, each coupled to five percentages of sand. The results obtained show that the geotechnical characteristics subjected to the study are much improved: the plasticity index goes from 39.58% for the Karal alone to 32.10% for the 70K+30S combination, i.e. a decrease 7.48%; the CBR after 4 days of immersion increases from 5.72% for Karal alone to 12.88% for the 70K+30S combination, an increase of more than double the value of Karal alone, just as the linear swelling decreases from the value of 3.66% for the Karal alone to 1.25% for the 70K+30S combination, i.e. a decrease of more than half of the swelling of the Karal alone. But these lithostabilization results simply allow use on a platform according to CEBTP specifications for roads with low traffic in tropical areas (see Table 7).

Table 7. Results obtained on the Karal of Dabanga and specifications of the CEBTP

Mixtures and CEBTP specifications	**Ip (%)**	**CBR (%)**	**Linear swelling (%)**	**Observations**
Platform or subgrade: specifications	< 40	> 5	< 3%	-
Base layer: specifications	< 25	> 25	< 2,5%	-
Base layer: specifications	< 20	> 60	< 1%	-
Karal of Dabanga: Measurement	39,58	5,72	3,66	Ok for limited use only in Platform, but not in foundation layer and neither in base layer for too high Ip and insufficient CBR.
75% Karal + 25% Sand: Measurement	32,84	11,20	1,86	
70% Karal + 30% Sand: Measurement	32,10	12,88	1,25	

6. CONCLUSION

The objective of this article was to show the influence of lithostabilization on the improvement of certain geotechnical characteristics of the Karal of Dabanga, used as road material. More specifically, it was a question of seeing how the plasticity, the CBR bearing capacity after immersion and the linear swelling of the Karal of Dabanga are improved when the latter is litho-stabilized with the sand of Mayo Kaliao in Maroua. The CEBTP specifications ([3] & [4]) relating to the dimensioning of low-traffic roads in the tropics were used as a tool for verifying the conformity of the results obtained on the Karal-Sand mixtures with a view to their use as a platform or in pavement body. The results obtained show that the Karal of Dabanga litho-stabilized with 30% of Mayo Kaliao sand is compliant for use only as a Platform, but not as a foundation layer or as a base layer because of a Plasticity Index that is too high and insufficient CBR in accordance with CEBTP specifications. It would then be necessary to foresee in perspective the addition of hydraulic binders to the litho-stabilized Karal for its eventual use in road layers.

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