Assessment Of Laterite Suitable For Road Construction In Bafang Area (West-Cameroon) Based On Physical Properties, Geo-Environmental Factors And GIS Software

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Abstract— **The gravelly lateritic soils used as raw materials in road construction, have been the subject of evaluation in order to determine their spatial distribution in Bafang area (West-Cameroun). Thereby, field surveys, geotechnical properties and GIS tools by Inverse Distance Weighted (IDW) and Boolean modeling have been used to achieve the purpose. Focused on the field surveys and geotechnical properties, two geotechnical soils categories have been identified: (i) clayed to loamy sand and gravel known as gravelly lateritic soils and (ii) clayey soils which regroup fine grained lateritic soils and very fine grained lateritic soils. Clayey soils contain more than 35% of particles passing through 0.08 mm sieve mesh. They are grouped within the A-7-5 class and have I_G values more than 2. Whereas the gravelly lateritic soils have less of 35% of fine particles (size less than 0.08 mm) and their I_G values are less than 2. These materials are classified within A-2-5 and A-2-7. By combined field surveys and geotechnical properties on GIS tool, the gravelly lateritic soils are concentrated on basaltic formation which covers 52 km^2, accounting 81.3% of the entire area. These loose materials have spread out on 28.8 km^2 and 42.5 km^2 corresponding respectively to favorable elevation ranges and favorable slope ranges of the study area. The IDW interpolation and Boolean combination have restricted considerably and respectively the surface of the gravelly lateritic from 8 km^2 to 2.1 km^2. The different processes have attested that the spatial distributions of gravelly lateritic soils used in road construction are constrained by physical properties, geo-environmental factors and GIS. Therefore, mapping approaches considered here might be suitable to delineate the gravelly lateritic soils distribution within the lateritic materials of the Inter-tropical highland area.**

Keywords— **Gravelly lateritic soils, road construction, IDW, Boolean modeling, GIS, Bafang, Cameroon Highland**

I. INTRODUCTION

Lateritic soils are either red when they are more concentrated in hematite or yellow if goethite is predominant **[3]**. These are soils rich in hematite-kaolinite-goethite and formed by progressive enrichment of iron and silica, from the parent rock to the top of the profile **[8]**. They are abundant in either iron or aluminum, or both; hence there are either ferruginous soils or ferrallitic soils **[27; 12; 24]**. Most of these soils are developed on basic eruptive rocks and cover the intertropical zone **[2]**. These supergene materials are subdivided into several categories: (1) lateritic duricrust; (2) lateritic shells; (3) gravelly laterite and (4) fine grained laterite. They cover about 70% of the cameroonian territory **[25; 15]**. In this country, as elsewhere in the intertropical zone, gravelly lateritic soils are solicited to carry out civil engineering works. They are used to make the sub-base layer of flexible pavements and sometimes their base layer **[25; 1; 6; 7]**. Moreover, these materials are also used for building dams, breakwaters and rehabilitation or construction of earthen roads (rural roads). TPSSA **[29]** certifies that on 50 000 km of cameroonian road network, about 18 016 km are unpaved roads and 27 693 km are rural roads. With regard to the road infrastructures to be implemented in order to promote national exchanges, the gravelly lateritic soils are a raw material in the civil engineering sector. The establishment of the roads infrastructures requires the contractors companies to carry out the preliminary work such as survey and basic geotechnical analyzes (grains size analysis and Atterberg limits) on these soils, in order to determine quarries where raw materials corresponding to the precise road construction can be borrowed. This preliminary work is imperative because the gravelly lateritic soils are not common. They form pockets of concentration at various locations, such as in the Highlands of Western Cameroon. This seems to make the road construction more expensive and extend regularly their delivery date. Thus, to solve this type of problem during the execution of road construction works, the establishment of a geotechnical database on gravelly lateritic soils through their mapping is fundamental. For this reason, this research focuses on the determinations of the grains size distribution and Atterberg limits of lateritic soils samples of the Bafang area. This involves their classification in the Highways Research Board (HRB) standard and finally assessing the spatial extension of gravelly lateritic soils based on geo-environmental factors and Geographic Information System (GIS).

GIS is a software program which captures, stores, analyzes, manages data and associates attributes that are spatially referenced to the earth. GIS technology can be used for scientific investigations, resource management, asset management, environmental impact assessment, urban planning, cartography and route planning **[14]**. GIS operate with several softwares programs containing many tools. For Tematio et *al.* **[28]**, GIS is an excellent software system for mapping duricrust bauxitic ore by supervised classification and band ratio on Landsat ETM+ imageries methods. Momo et *al.* **[18]** have proposed that encrusted bauxitic surfaces can be assessed by GIS through Boolean modeling and kriging methods. At same time, GIS is used to evaluate the soils fertilities in agricultural domain by IDW, fuzzy logic and Ordered weight average methods **[17]**. In addition, Walke et *al*. **[31]** show that multi-criteria analysis method in GIS, enables the classification of agricultural soils relying on their fertilities degree. Based on soils properties, urban development also uses GIS. Therefore, Xu et *al.* **[33]** have demonstrated that K-means clustering and back propagation neural network in GIS are fundamental tools for planning urban development. Furthermore, IDW in GIS have also used to plane the urban development **[34]**. GIS occurs in many domains and allows decisions making. It is a tool which must be consulted before initiating a development project in a locality. Hence, GIS promotes the sustainable development. Based on these previous studies, lateritic soils have not been evaluated concerning their spatial distribution using GIS and taking into account their geotechnical properties and geo-environmental parameters.

II. MATERIAL AND METHOD

A. *Natural Framework of the study*

Geographically and geologically, the studied area is situated within the Western Cameroon Highland in the central part of Cameroon Volcanic Line (Fig.1). This zone is in the South-West of Bangou Mountain. It is bounded by 05°05’02,96’’ to 05°09’07,40’’North as latitudes and the meridian 10°08’03,70’’ to 10°13’24,44’’East (Fig. 2).

On the administrative point of view, the study area belongs to Bafang subdivision which is located at Western Cameroon region. It is formed by villages as Bafang, Babone, Baboutcheu-Ngaleu, Bankondji and Bassap. This studied area covers 64 km^2. The vegetation is agro-forestry, with swampy areas being occupied by raffia palm forests relics. The hydrography of the area shows a dendritic network (Fig. 2). According to Tchuimegnie et *al.* **[26]**, the predominant rock is alkaline basalt. But during the field trip of this study, grained to coarse grained granites outcrops have been identified at different places.

B. ***Field method***

During the field trips, an auger was used to collect 200 samples from the entire area in order to recognize the soils profiles features. The surveys map was established and permitted to determine the points where different wells must be realized. Thus, thirty manual wells of three meters depth were dug and the soils profiles were described through them. The descriptions of different soils profiles were realized according to Maignien **[13]**. Here, thickness, color, texture, structure have considered for making differences between all the soils profiles. The color of the soil samples was determined using a Munsell color chart **[19]**.

For physical laboratory characterization, thirty samples were collected by blending materials of different horizons of the profiles without those of horizon A. These sampling methods are closed to those adopted by civil engineering companies during the roads constructions works. This is why; the civil engineering companies constantly borrow laterites materials in quarries by mixing mineral horizon. In general, three main soils profiles have been retained for this research paper.

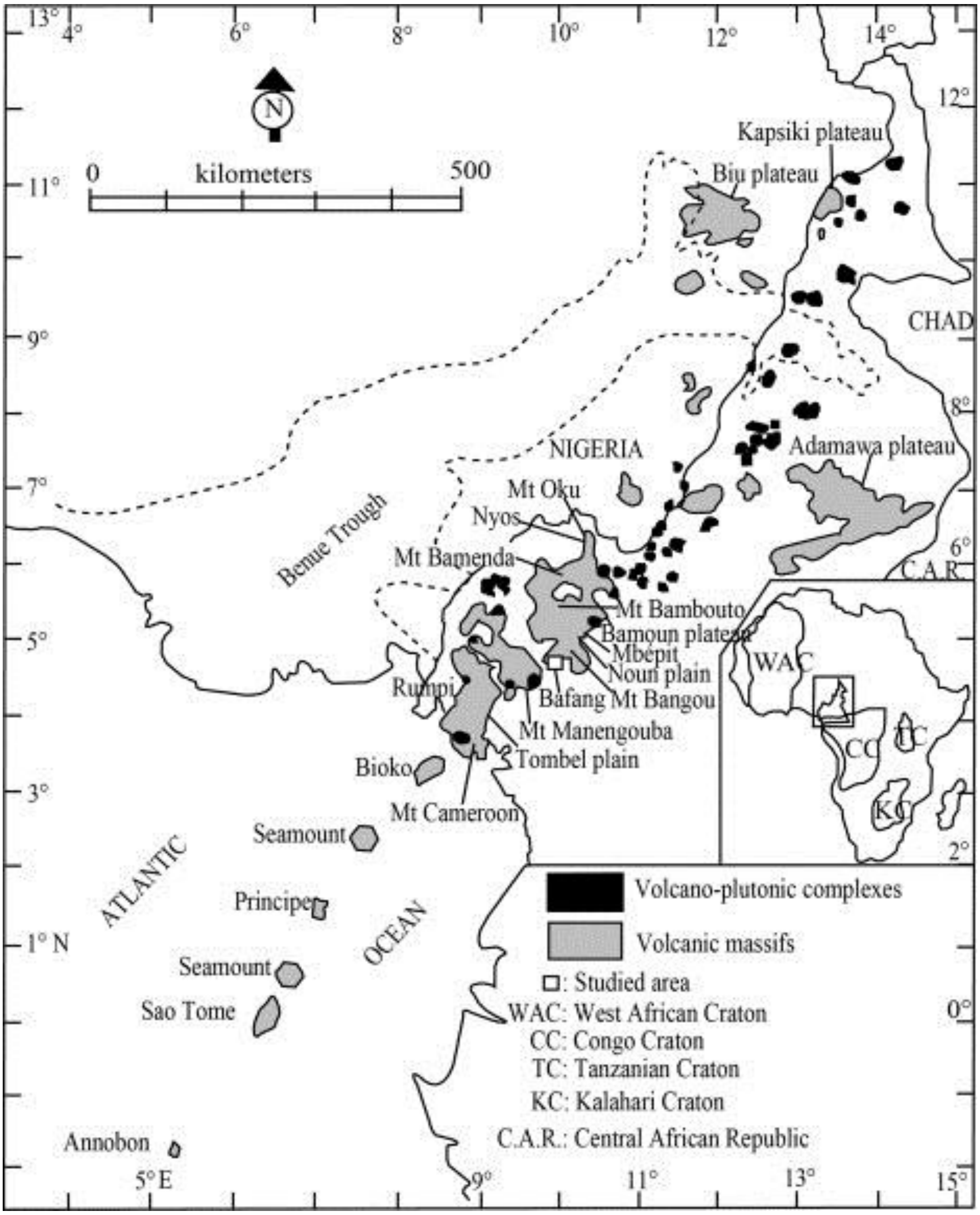

Figure 1: Location of Bafang on the Cameroon Volcanic Line adapted by Tchuimegnie et *al.* **[26]**

C. *Laboratory methods*

C.1. Grain size analysis

The grain size analysis of the different lateritic soils was performed according to the specification NF P 94-056 **[22]**. Based on this standard, the grain size distribution curves were plotted with size fractions larger than 80µm, obtained by dry sieving through a series of sieves of decreasing mesh sizes. The size fractions less than 80µm in diameter were obtained by hydrometer analysis.

C.2. Atterberg limits

Atterberg limits were used to determine the plasticity index of the studied materials. The liquid limits were determined using the Casagrande apparatus while plastic limits were identified on the rods of 15 mm length and about 3 mm of thickness according to the NF P94-051 **[21]** specification. According to this specification, $I_P = W_L - W_P$ **(1)**

I_P is the plasticity index; W_L is the liquid limit and W_P represents the plastic limit.

C.3. Geotechnical classification method of laterite

The geotechnical characteristics have permitted the definition of the taxonomy of loose weathered materials formed on Bafang basalts according to geotechnical standard (chart) called Highway Research Board (HRB). The Group Index (I_G) is given by the equation 1:

$$I_G = 0.2a + 0.005ac + 0.01bd \qquad \textbf{(2)}$$

a is a value which depends on the percentage of particles passing through mesh sieve 0.08 mm named X: if $X \leq 35$ then a = 0; if $35 < X < 75$ so $a = X - 35$ and $X > 75$ then a = 40.

b value represents the portion of passing percentage through mesh sieve 0.08 mm (X): when X< 15 then b = 0; if 15 < X < 55 so b = X – 15 and X > 55 then b = 40.

c relies on liquid limit (W_L) value: if W_L < 40, so c = 0; if 40 < W_L < 6 then c = W_L- 40 and if W_L > 60 then c = 20.

d is given by the plasticity index value (I_p): if I_P < 10 then d = 0; if 10 < IP< 30 then d = IP – 10; and if I_P > 30 so d = 20.

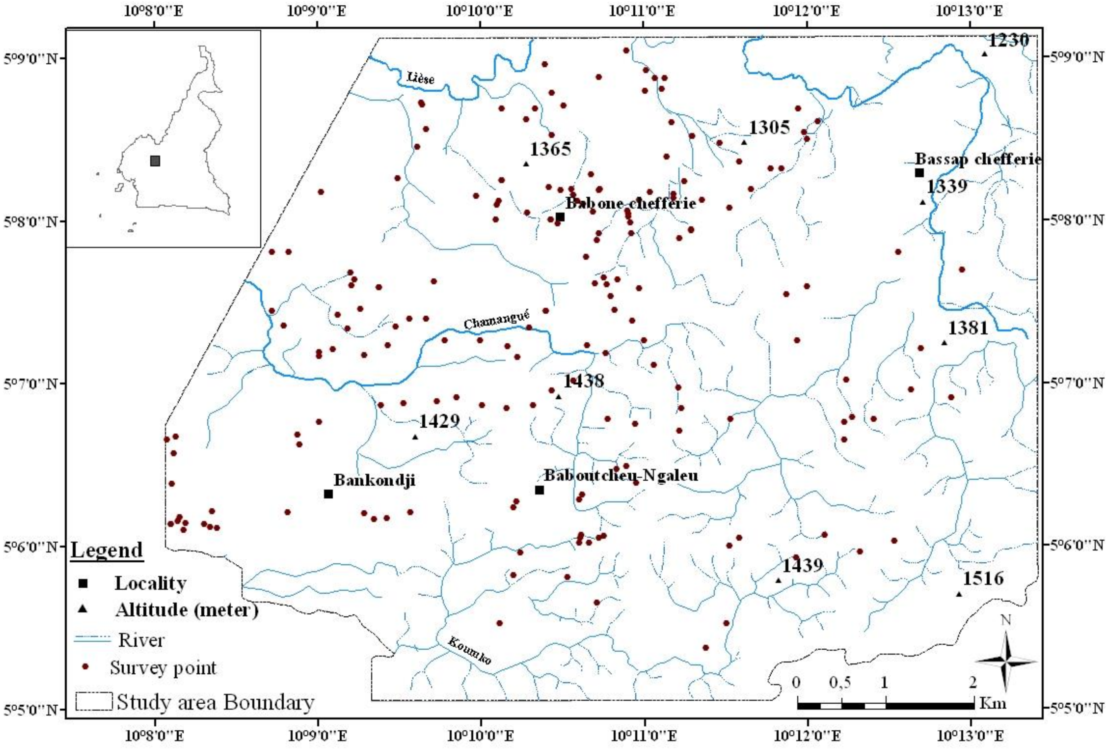

Figure 2: Survey map of studied zone

According to the precedent I_G equation, the HRB standard relies on the grain size and Atterberg limits. This geotechnical specification is preferred by many civil engineering consultancies and civil engineering companies in Cameroon. It is important to note that for using the specification NF P 94-056 **[22]** with HRB standard, mesh sieve 0.075 mm size is replaced by mesh sieve 0.08 mm.

C.4. Mapping method

For evaluating the Bafang gravel lateritic soil, Boolean model was used. This model investigates the relationship between different natural features like geology, slope, elevation through their maps and obviously the interpolation map of geotechnical soil distribution based on I_G values. The different thematic maps (geologic, elevation and slope maps) have been realized through Shuttle Radar Topographic Mission (SRTM). The interpolation applied on 30 samples, has relied on Inverse Distance Weighted (IDW) because Mokarram and Hojati **[17]** certify that it is a good method to interpolate randomly sampling points.

The IDW model has been used for interpolating the effective data in determining the soil suitability for civil engineering work such as group index (I_G). The IDW interpolation explicitly implements the assumption that things which are closed to each other, are more alike than those which are not. To predict a value for any unmeasured location, IDW will use the measured values surrounding the prediction location. The assumed value of an attribute z at any un-sampled point is a distance-weighted average of the sampled points lying within a defined neighborhood around that un-sampled point. According to Burrough and McDonnell **[5]**, this value is a weighted moving average.

$$\mathbf{Z(x_0)}=\frac{\sum_{i=1}^{n} z(xi)\,di^{-r}}{\sum_{i=1}^{n} di^{-r}} \qquad \mathbf{(3)}$$

where $\mathbf{x_0}$ represents the estimation point, xi are the data points within a chosen neighborhood. R corresponds to power factor and **di** is distance between unknown point $\mathbf{x_0}$ and known point xi, and i is the relative point from a set of points n. n is from 0, 1, . . ., n. Finally **z(xi)** is real value of **xi** and $\mathbf{z_0}$ is estimated value in $\mathbf{x_0}$. Power parameter (**r**) is related to the distance by **di**. The negative sign before **r** is because of inverse relation of d and estimated value. As distance increases from interpolated point weight decreases. Greater values of **r** assign greater influence to values closest to the interpolated point, with the result turning into a mosaic of tiles with nearly constant interpolated value for large values of **r**.

The Boolean method, it is based on reclassification of the input maps into only two classes. The reclassification method consists of realizing the maximum and minimum evidential score classes (0 or 1). Reclassified maps are combined logically according to a set of steps called inference network, which reflects the inter-relationships of processes controlling the occurrence of a geo-object and spatial features indicating the presence of this geo-object. Finally, the output of combined evidential maps via Boolean logic modeling is a two-class map. The first class represents locations where all of the prospective recognition criteria are satisfied, while the second class represents locations where at least one is unsatisfied.

The study was carried out with ArcGIS 10.0 program using a three step methodology including: (i) gathering spatial data into a GIS, (ii) extracting spatial evidential data and creating derivative maps to be used as spatial evidence of gravel lateritic soil concentration, and (iii) integrating the spatial evidence map to create gravelly lateritic soils distribution map.

III. RESULTS

A. Field result

The field works have permitted the identification of: (i) eight soils profiles corresponding to gravelly lateritic soils; (ii) fourteen soils profiles linked to fine grained lateritic soils and finally (iii) eight soils profiles closed to very fine grained lateritic soils.

The profiles of gravelly lateritic soils are enriched of indurated variable sizes particles along their different horizons (Fig. 3). Their structure is granular and the texture confirms their loamy-sand character. Thicknesses of horizon B are greater than 200 cm. The color of that principal exploitable horizon varies from dark red to dark reddish brown.

Concerning the fine grained lateritic soils, there are two types of profiles. For the first one (Fig. 4), the horizon B here is divided in two parts from the bottom to the top. The bottom part named horizon BC, is a blended materials formed by indurated variable sized particles and fine grained particles. Their color is dark red to yellow. The top part corresponding to horizon B is generally dark brown red and is formed by fine grained size particles. The second one (Fig. 5); the very fine grained soils profiles are constituted of nodules scattered along the horizon B. Their colors are dark brown to yellowish brown in the constantly humid valley area and dark red in none humid area. On the whole, those types of soil are characterized by mineral horizon with thicknesses greater than 200 cm and their texture is silty.

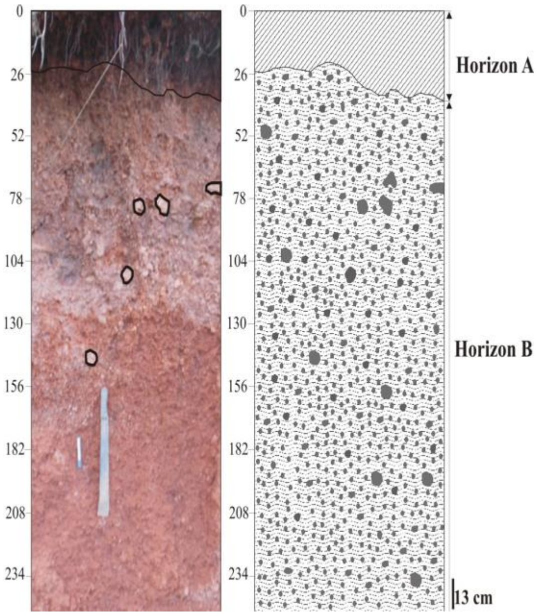

Figure 3: Bafang gravelly lateritic soil profile

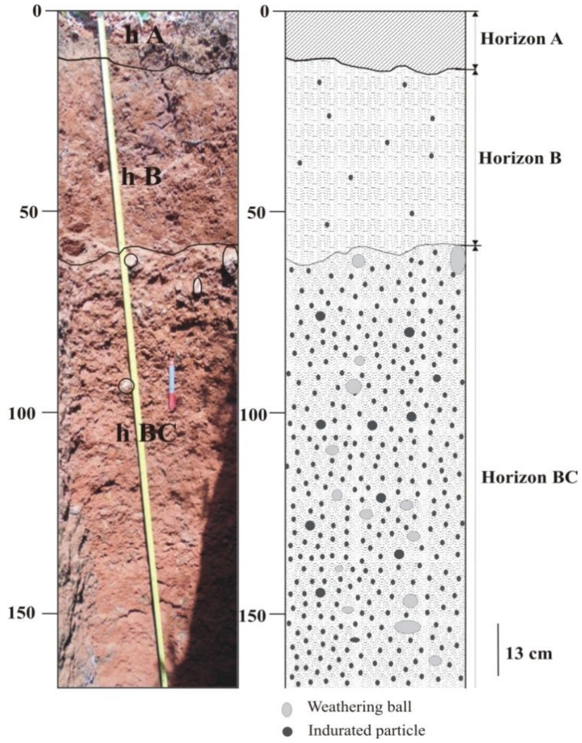

Figure 4: Bafang fine grained lateritic soil profile

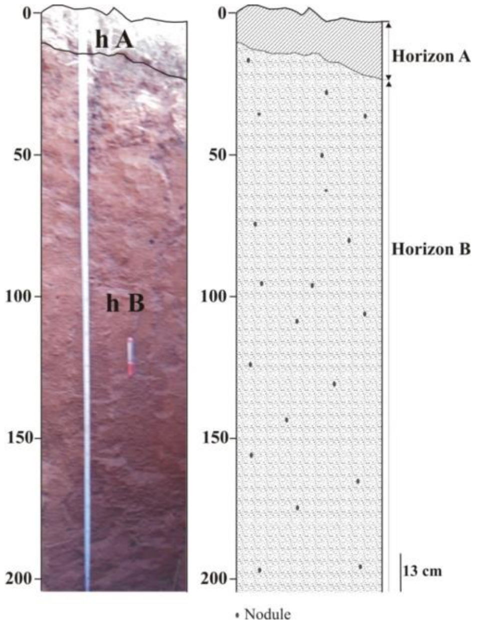

Figure 5: Bafang very fine grained lateritic soil profile

B. *Physical properties of lateritic soils formed on basalt and their taxonomy*

The Bafang gravelly lateritic soils contain different particles in term of sizes; hence they are well graded (Fig.6). The proportions of particles more than 5 mm in size, vary from 48 to 63%. In this fraction, coarse particles represent 10 to 28%. The sandy grains form the least represented fraction. Their percentages are between 7% and 16%. The fine grained particles (X) are less than 35% in quantity (Fig.6 and Tab.1). These fine grained fractions make up the main part of mortar grains. On the mortar part, the plasticity index values are from 8 to 11.8; obtained by the differences between the liquid limit values (from 57% to 66%) and the plasticity limit values ranging from 47.7% to 56.4 %. Based on the amount of particles passing through 0.08 mm sieve mesh and the values which characterize the Atterberg limits, the Bafang gravelly lateritic soils have 0 as group index (Ig). Thereby, they are named clayed to loamy sand and gravel according to HRB specification. They are A-2 group of loose material and are from A-2-5 to A-2-7 (Tab. 2).

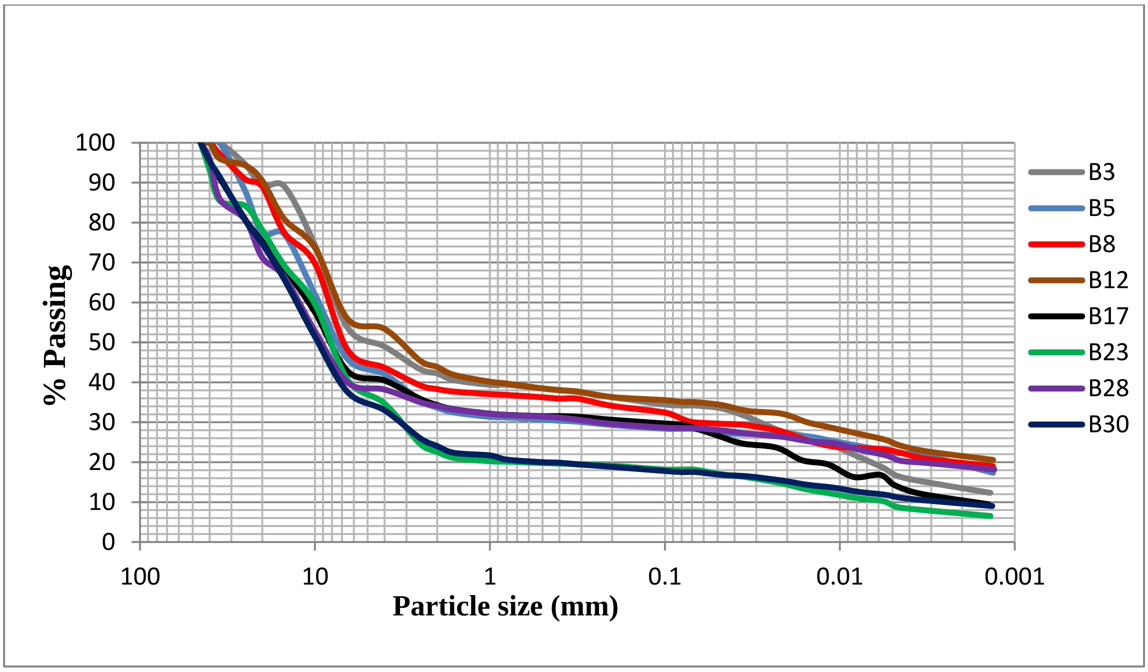

Figure 6 : Grain size distribution curves for Bafang gravelly lateritic soils

For the Bafang fine grained lateritic soils, the presence of different grains sizes are as in equal the one in the lateritic gravel soils. However, the particles more than 5 mm in size, form the moderate fraction (Fig.7). Their proportions evolve from 26 to 56% with lower coarse grained quantities. Moreover in the lateritic gravel soils, the sandy particles represent about the same proportion within fines lateritic soil. Sandy and grained particles more than 5 mm in size are lower in term of proportion than fine particles passing through 0.08 mm; where their proportions range from 38% to 66%. Thus, the lots of fine grained material involve the liquid limit and plasticity limit values ranging respectively from 58% to 75% and from 42% to 60%. This implies the plasticity index values which vary from 12 to 21. According to the proportion of grains size less than 0.08 mm and the Atterberg limits, the group index (Ig) values of these types of soils range from 1 to 15 and characterize the soils materials called clayed soil. The clayed material corresponds to A-7 group and A-7-5 sub-group defined by HRB specification (Tab. 2).

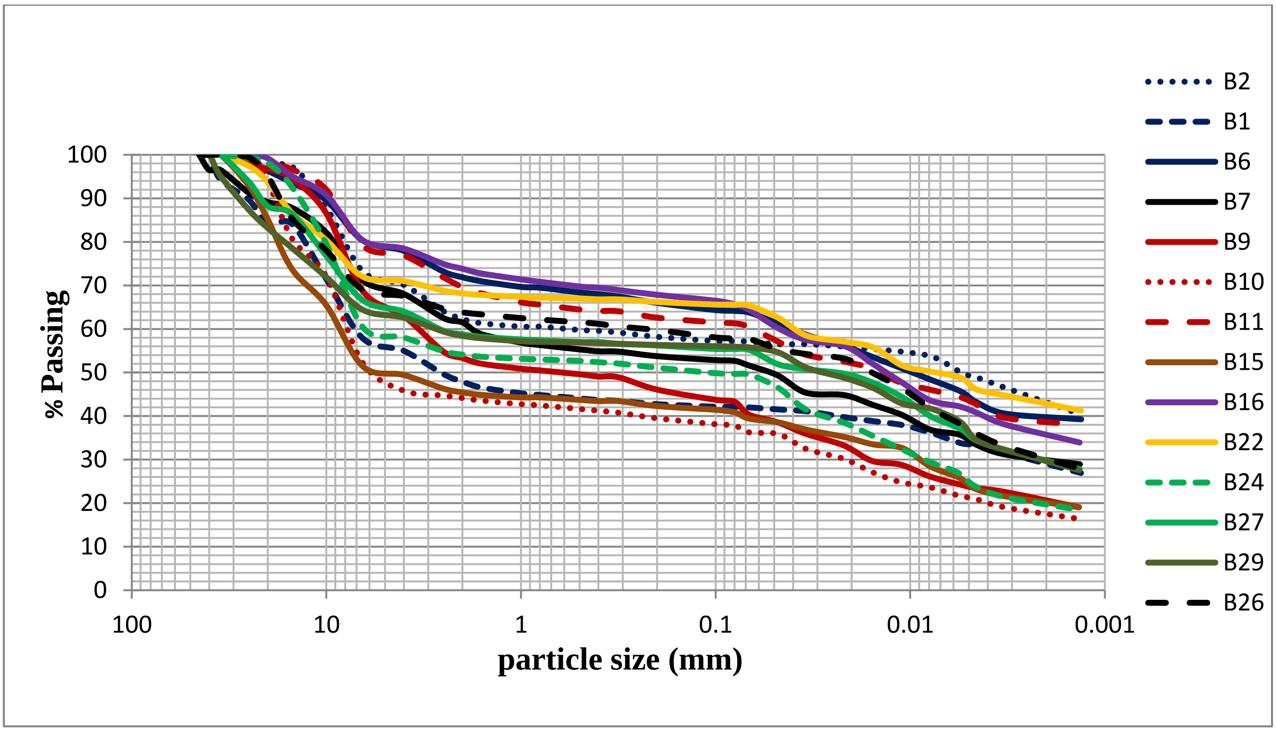

Figure 7: Grain size distribution curves for Bafang fine grained lateritic soils

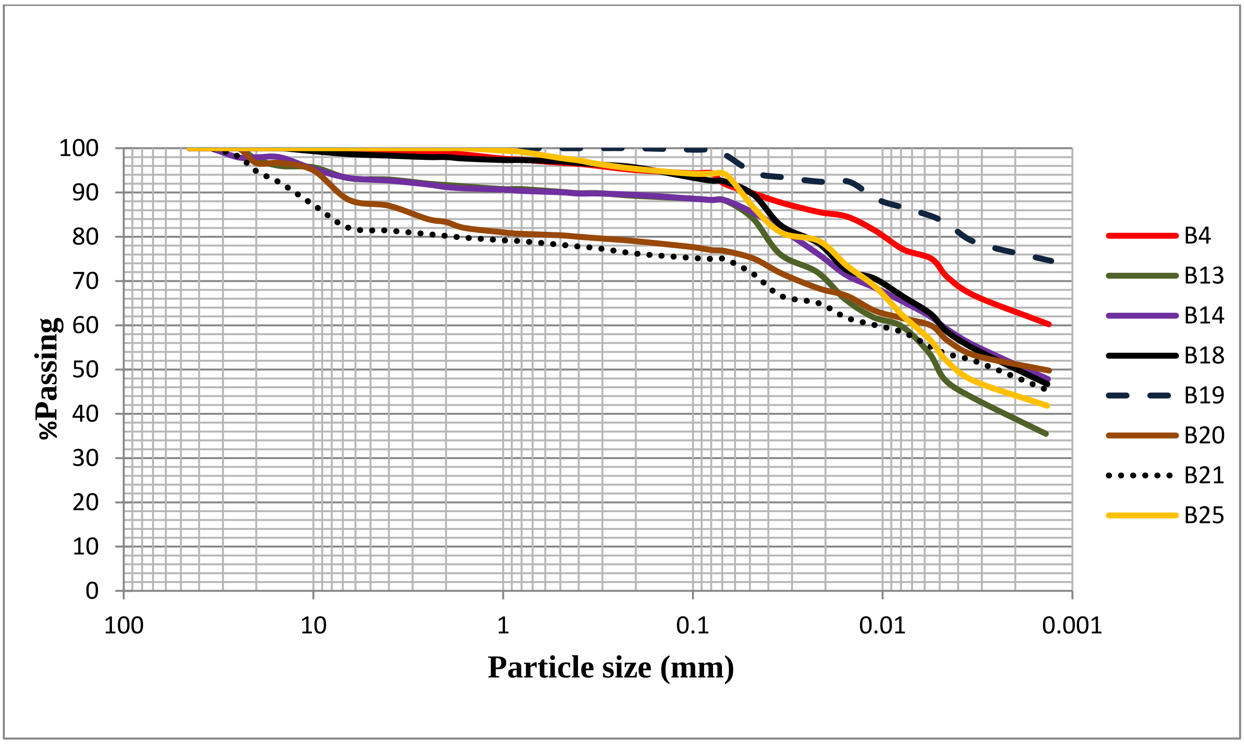

Figure 8: Grain size distribution curves for Bafang very fine grained lateritic soils

Finally, the very fine grained lateritic soils are enriched in grains less than 0.08 mm in size (fig. 8 and tab. 1). Their total amounts in these types of soils are between 75% and 99%. Beside the fine grained particles, the proportions of grains more than 5 mm in size are the lowest, with the coarse grained proportions less than 5%. The fines sands particles are the main constituent of sandy part, with the proportions from 8 to 19%. The highest amount of fine grains contents implies the following ranges values of liquid limit, plastic limit and plasticity index respectively: 48% to 73; 43% to 52% and 16 to 25. These different values of Atterberg limits associated to fine grained particles (less than 0.08 mm in size) allow calling them clayey soils. They are referred to A-7 group and A-7-5 sub-group defined by HRB specification as fine lateritic soils.

Table 1: Parameters of geotechnical taxonomy of Bafang lateritic soil according to HRB specification

Type of soil	Sample	X (%)	W_L (%)	W_P (%)	I_P (%)	Group	Sub-group	I_G	Name of the soil according to HRB specification
Gravelly lateritic soils	B3	34	62	55.1	10.9	A-2	A-2-7	0	**Clayey to loamy sand and gravel soil**
	B5	29	60	49.4	10.6			0	
	B8	31	64	53.6	10.4			0	
	B12	35	64	54.0	10.0			0	
	B17	29	57	47.7	09.3		A-2-5	0	
	B23	18	60	51.3	08.7		A-2-7	0	
	B28	29	66	54.2	11.8			0	
	B30	18	65	56.4	08.6		A-2-5	0	
fine grained lateritic soils	B1	42	72	57.2	14.8	A-7	A-7-5	03	**Clayey soil**
	B2	58	72	58.5	13.5			08	
	B6	64	68	53.3	14.7			11	
	B7	53	74	59.6	14.4			07	
	B9	43	68	55.7	12.2			03	
	B10	38	71	58.9	12.1			01	
	B11	61	68	52.5	15.5			10	
	B15	41	61	48.7	12.3			02	
	B16	66	68	49.1	18.9			14	
	B22	66	66	45.8	20.2			15	
	B24	50	60	45.7	14.3			06	
	B26	58	75	58.7	16.3			10	
	B27	55	61	45.1	15.9			8	
	B29	60	58	42.6	15.4			10	
very fine grained lateritic soils	B4	94	72	47.6	24.4	A-7	A-7-5	18	**Clayey soil**
	B13	88	68	50.2	17.8			15	
	B14	88	66	47.7	18.3			15	
	B18	93	62	43.2	18.8			16	
	B19	99	72	50.8	18.2			15	
	B20	77	73	52.1	20.9			16	
	B21	75	66	49.6	16.4			15	
	B25	94	71	50.8	20.2			16	

C. Approaches for mapping lateritic gravel soil

C.1. Favorable geo-environmental factors

The study area is characterized by the predominance of alkaline volcanic rock especially basalt. It covers about 52 km^2, hence 81.3% of this entire area (Fig. 9; Tab. 2). This geological feature is dated from 10 to 6 Ma ago **[26]**. Their weathered materials are interesting in term of thickness and extension; whereas basalt outcrops at the top points of some hills and some riverbeds. In general, basaltic formation encircles granite rock. This last one represents about 18.7% in term of extension on the entire area. The granite is weakly weathered and their weathered products are mostly clayey. This rock outcrops everywhere it is found. That is why, it is considered as unfavorable rock concerning this study (Fig. 9).

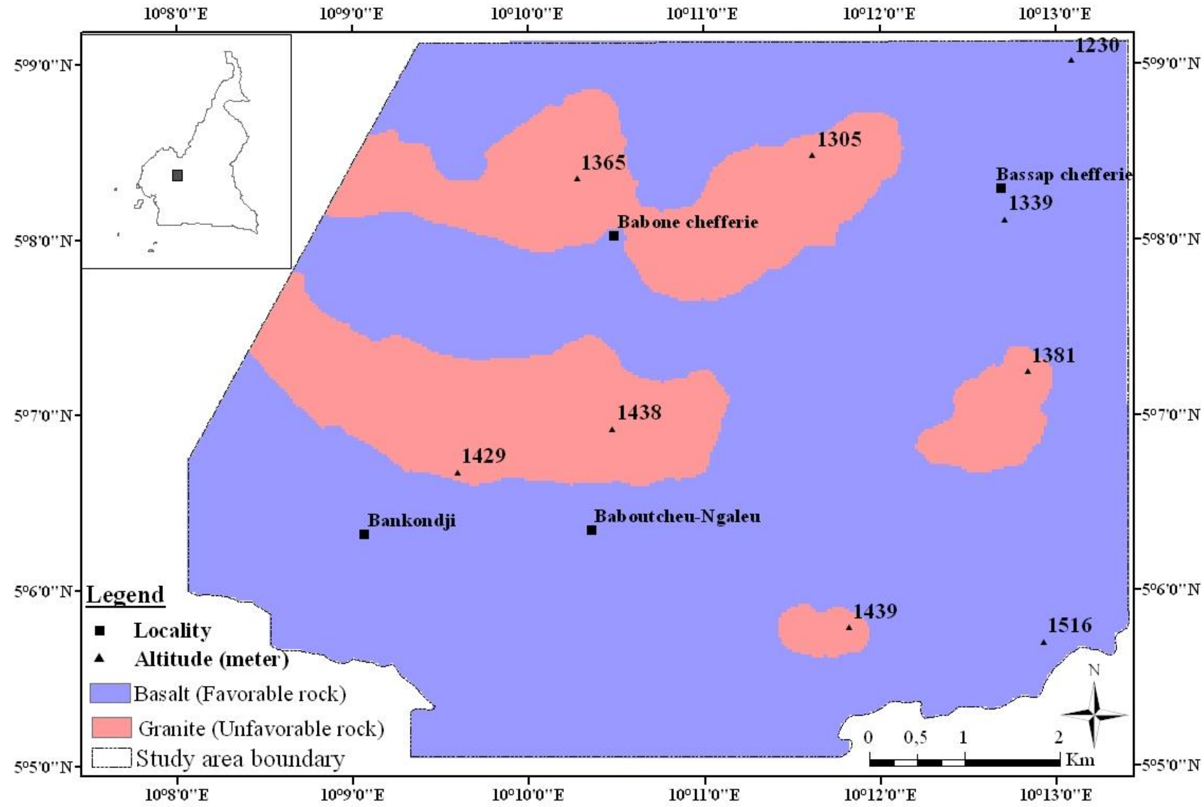

Figure 9: Influenced of lithology on gravelly lateritic soils distribution

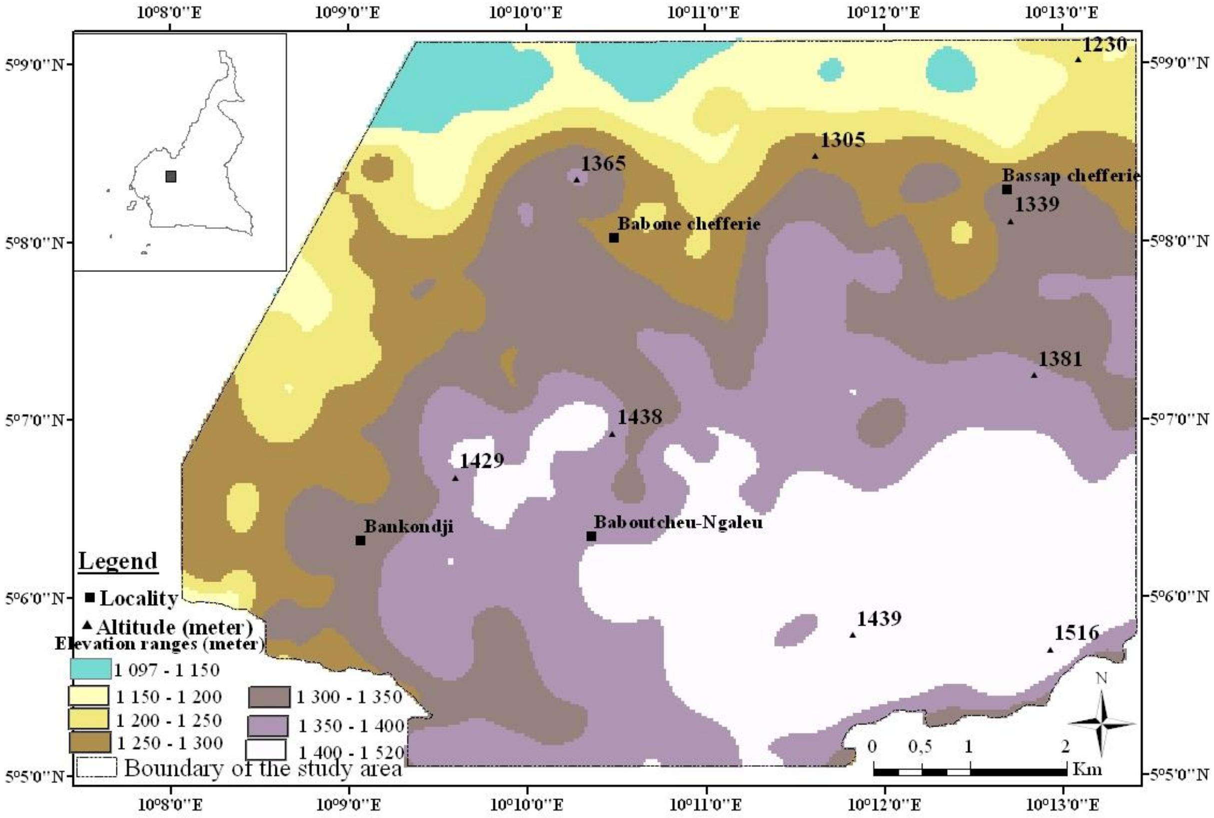

Figure 10: Elevations map

Concerning the elevation, the lowest point of the study area is about 1097 m and the highest point is 1516 m (Fig.10). The elevation map permits the distinction of seven elevations ranges after classification: 1097 m-1150 m; 1150 m-1200 m; 1200 m-1250 m; 1250 m-1300 m; 1300 m-1350 m; 1350 m-1400 m and 1400 m-1516 m. The elevation map has been combined with survey map. After accurately analysis of the combined map, the following elevations ranges are considered to be favorable for gravelly lateritic soils. There are: 1150 m-1200 m; 1250 m-1300 m and 1350 m-1400 m. Therefore, the favorable elevations ranges spread out on 28.8 km^2, accounting 45% of the total study area (Fig.11; Tab. 2).

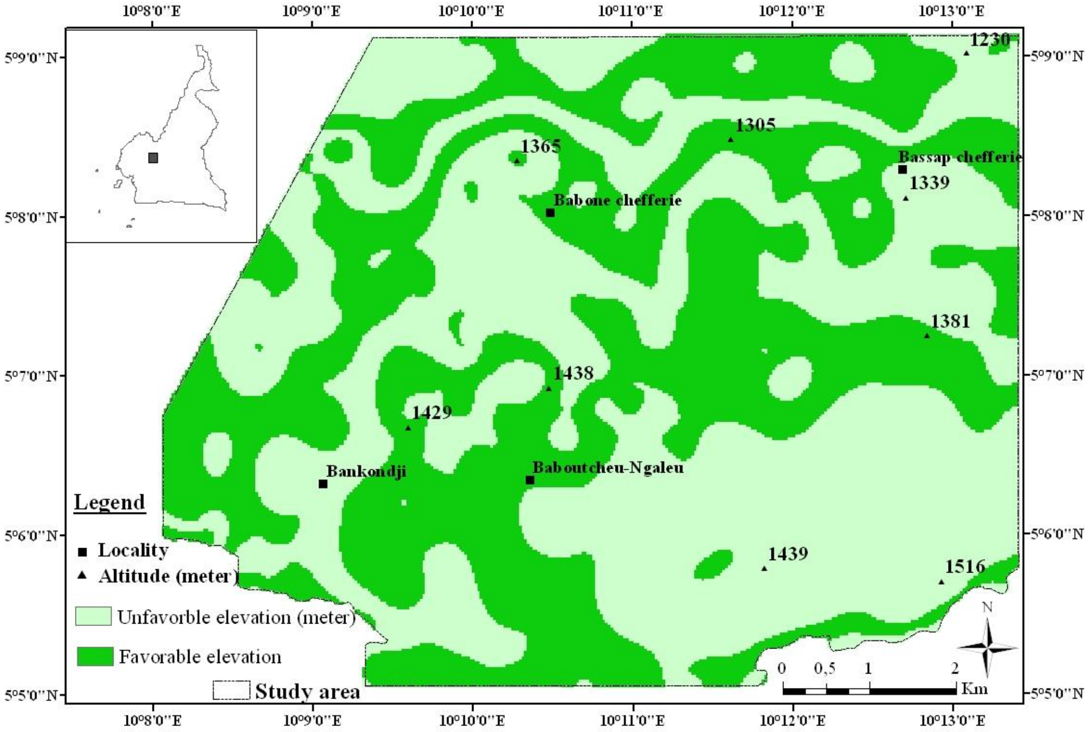

Figure 11: Influence of elevations on gravelly lateritic soils distribution

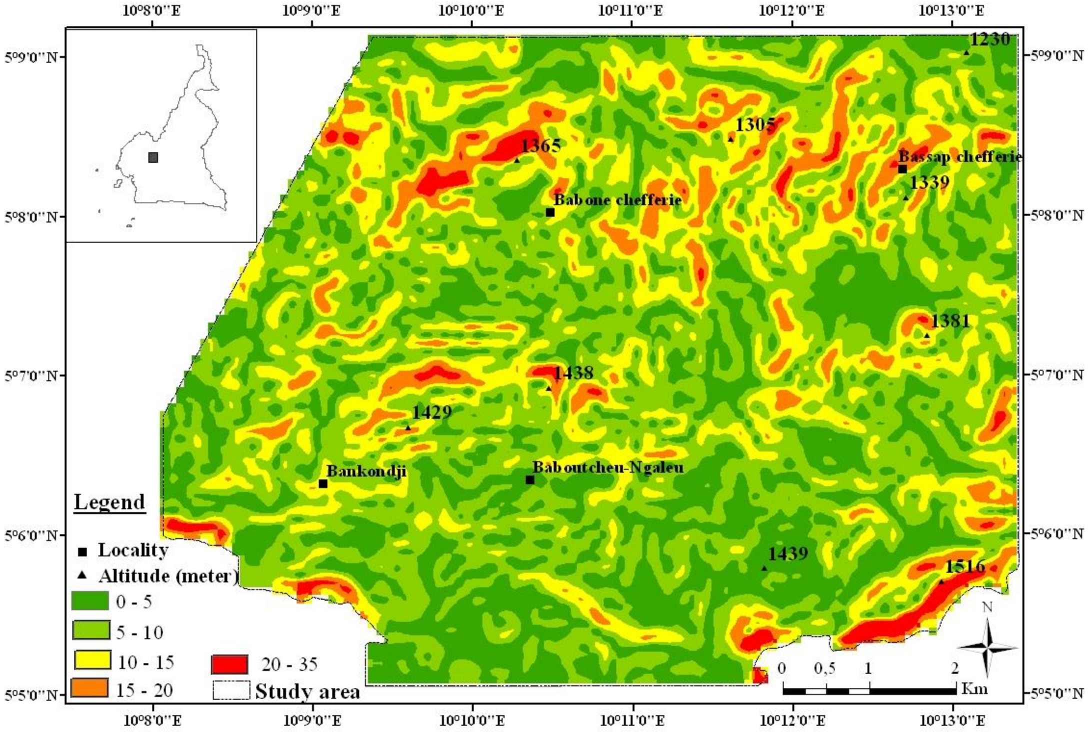

Figure 12: Slope map

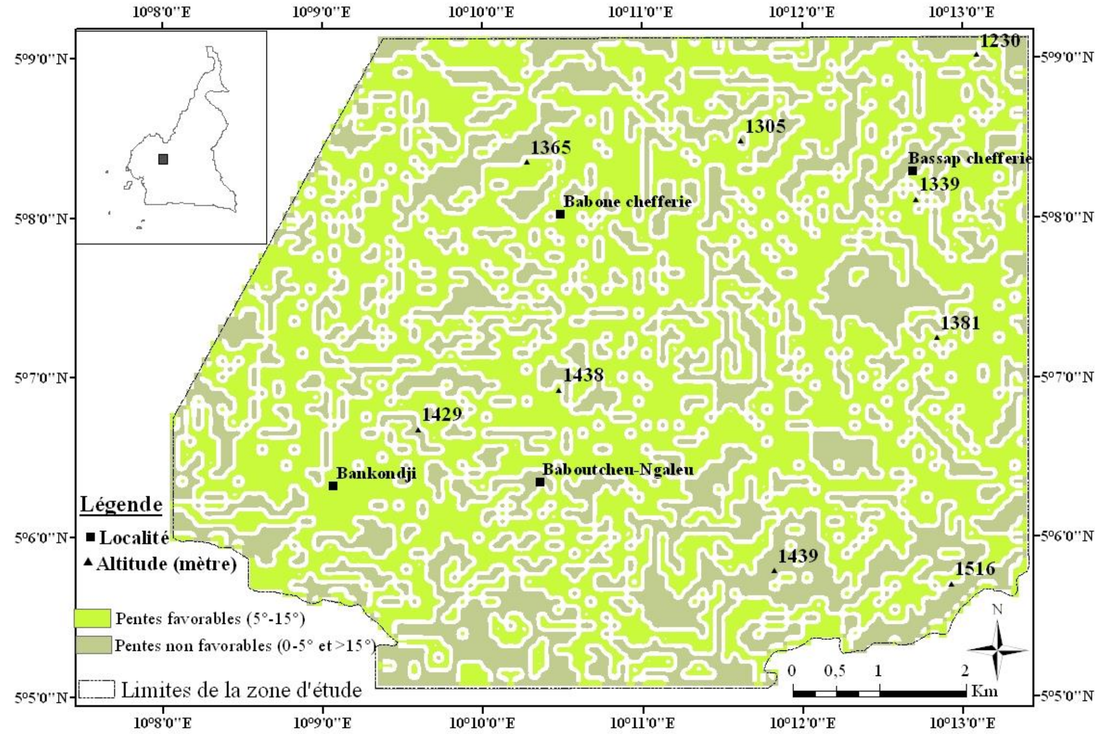

Figure 13: Influence of slopes on gravelly lateritic soils distribution

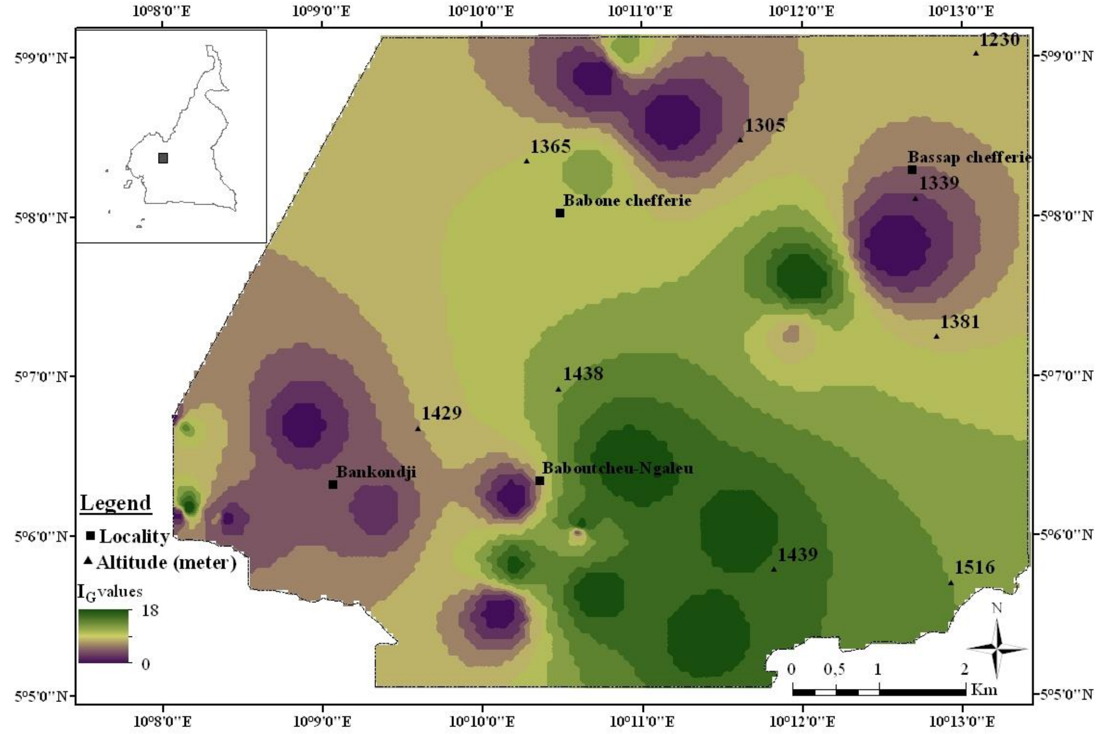

Figure 14: Soil distribution map according to I_G values through IDW interpolation

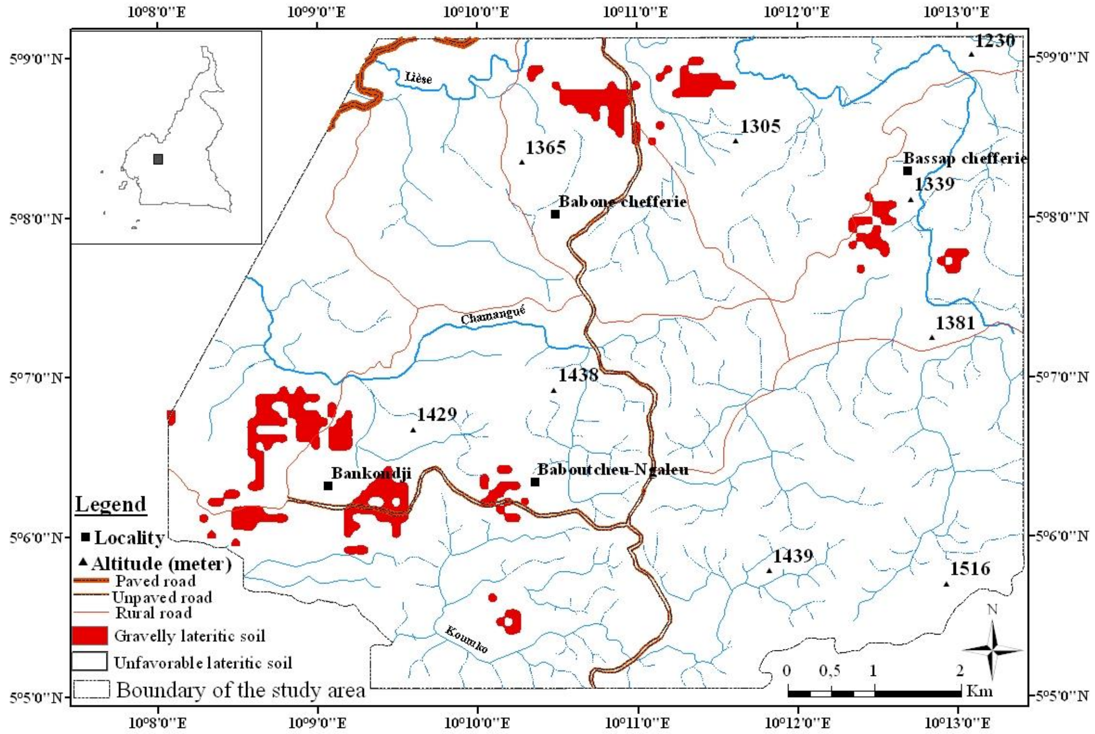

Figure 15: Bafang gravelly lateritic soils distribution map

As favorable elevation map has been realized, the favorable slope map follows the same procedure. Hence, the surface of 39 km^2 corresponds to favorable slope ranges. These favorable slope ranges are: 5°-10°and 10-15° (Fig.12 and Fig. 13; Tab. 2), accounting 60.9% of the total area. This is where potential gravelly lateritic soils are found within the study area.

C.2. Spatial distribution of Bafang gravelly lateritic soils

For the soils distribution, the extensions of the different categories of soil are obtained by using determinist model IDW. This map is based on I_G values which permit to determine the surface extension of gravelly lateritic soils, fine grained lateritic soil and very fine grained lateritic soil (Fig. 14). The gravelly lateritic soil surface is the favorable one and corresponds to surface where the I_G values are the lowest that is less than 2. This surface is encompassed by unfavorable material surface (fine grained lateritic soil and very fine grained lateritic soil). On 64 Km^2 of the entire area, the gravelly lateritic soils have been spread on about 8 km^2. Hence, the favorable area is 12.5% (Fig. 14). It forms different zones where gravelly lateritic soils are concentrated: north, northeast and southwest of the study area. After application of Boolean method on the different maps (Fig. 9; Fig. 11; Fig.13; Fig.14), the landscape of gravelly lateritic soils distribution has exhibited (Fig. 15). Thus, it constitutes the dissecting concentrations zones at north, northeast and southwest of the study area. Therefore, the gravelly lateritic soils distribution is sparse in those geographical zones of the study area. Their total extension surface is 2.1 km^2, corresponding to about 3.3% of the study area.

IV. DISCUSSION

A. Physical properties of Bafang gravelly lateritic soils and their taxonomy

The Bafang lateritic soil formed on basalt can be divided in two types of soils according to HRB: (1) clayey to loamy sand and gravel soil and (2) clayey soil. These two types of lateritic soils have investigated by Sikali and Mir Emérati **[25]**; Attoh-Okine **[1]**. Concerning the clayey to loamy sand and gravel, Fekpe and Attoh-Okine **[6]**; Frempong and Tsidi **[7]**; Kassogue et *al.* **[11]**; Nyemb Bayamack et *al* **[23]** ; Issiakou Souley et *al.* **[9]**; Kamtchueng et *al.* **[10]** show that they are lateritic soils with less than 35% of fine grained particles passing through 0.08 mm sieve. It is loose material appropriate for road sub-base course in general; despite their plasticity status which is from less plastic to plastic. Moreover, they are suitable for road base course in case of light traffic. Udoeyo et *al.* **[30]** highlight that this category of loose material can be replaced 40% of alluvial sand in concrete. Therefore, their suitability is due to the lot of grained particles contents (> 0.08mm in size) which decrease the water retention within the soil material. The presence of lot of grained particles (sand, gravel) and coarse grained within the material increases the compaction strength and the wearing capacity of the pavement **[7; 9; 10]**. This enrichment in grained particles contents seems to be the fact that elements like Fe, Al, Ti remain in situ during the parent rocks weathering to form secondary minerals such as goethite, ilmenite, hematite, anatase, rutile **[8; 23; 9; 10]**. Although the clayey to loamy sand and gravel soil has abundant grained particles, there is very fine grained (<0.08 mm). This last one packs the grained particles and forms the binder. They are mainly clay in term of mineralogy like kaolinite. The kaolinite arises from combined elements silica and aluminum oxide which don’t leach in the supergene environment during the weathering process. These different approaches have confirmed by Tematio **[27]**; Giorgis et *al.* **[8]**. Thus, kaolinite is the one of the essential mineral constituent of this fine grained phase which influences the Atterberg limit parameters and involves the elevated plasticity index values **[32]**. Furthermore, the gravel lateritic soil of Bafang is very plastic silty soil according to Casangrande diagram (Fig. 16). The decrease of particles less than 0.08 mm from very fine grained lateritic to gravel lateritic soil can explain the reduction of plasticity from very plastic silt (Lt) to less plastic silt (Lp) respectively.

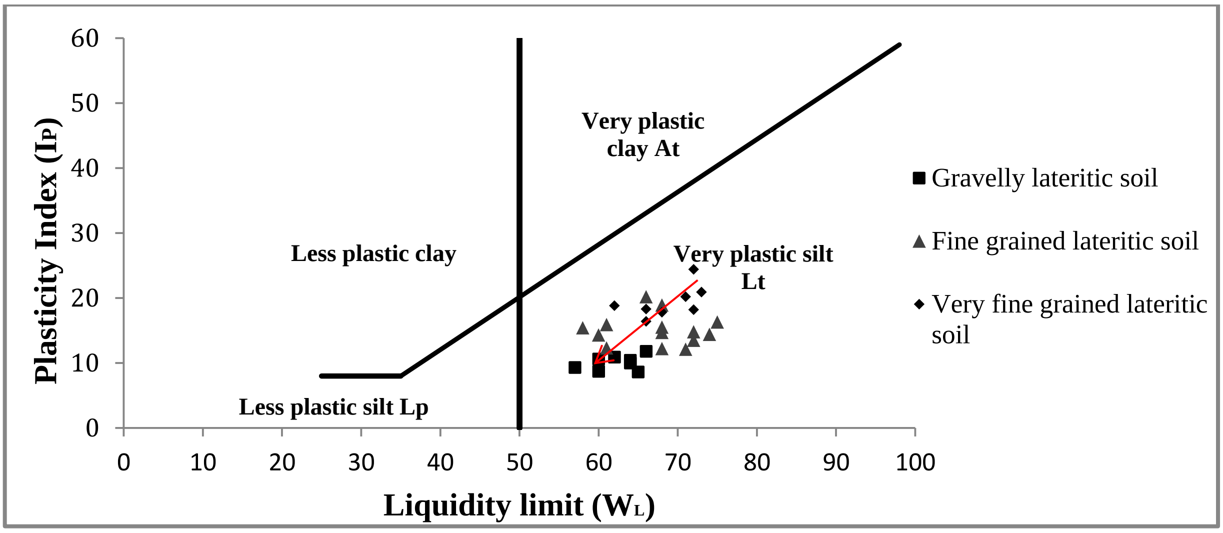

Figure 16: Casagrande chart classification of lateritic soils in the study area

B. *Spatial distribution of Bafang gravel lateritic soil*

The IG values of the Bafang laterite in general, range from 0 to 18. For the IG values Less than 2, the material is gravelly lateritic soil. The surface corresponding to these lowest series of IG values is weakly distributed compared to those having the higher IG values. This means that the zones of concentration of raw material, potentially used in road construction in Bafang area are very limited in term of spatial distribution. Nevertheless, the unusable laterites are widespread in this area. In general, the raw materials potentially used in civil engineering are scarce as revealed by Yilmaz **[34]**. This can be warranted by the influences of slope, elevation and lithology. Tematio et al. **[28]**; Momo et al. **[18]** confirm that slope, elevation and lithology are geo-environmental factors which delineate the spatial distribution of the raw material.

Thus, the spatial distribution of Bafang gravelly lateritic soil decrease from 8 km^2 to 2.1 km^2 with the application of Boolean modeling to different consideration parameters such as lithology (Fig. 9); elevation (Fig. 11); slope (Fig. 13) and I_G value interpolation. The extension of gravelly lateritic soils is mostly constrained by lithology; elevation; slope. Slope and elevation ranges corresponding to the gravelly lateritic soils distributions, are respectively gentle and flat. These different areas are well exposed by GIS tool.

Table 2: Evaluation of lateritic soils types based on their physical properties and geo-environmental factors of the study area

Type of lateritic soil	Physical properties	Geo-environmental factors			Appreciation
	I_G value range	Rock type	Elevation range	Slope range	
Gravelly lateritic soils	0-2	Basalt	1150 m-1200 m 1250 m -1300 m 1350 m-1400 m	5°-15°	Favorable
Fine grained lateritic soils	2-15	Basalt and granite	1097 m-1150 m 1200 m-1250 m 1300 m-1350 m 1400 m-1516 m	0-5° and >15°	Unfavorable
Very fine grained lateritic soils	15-20				

Table 3: Place of Bafang gravelly lateritic soil between other suitable laterite used as road construction material in some areas of the Inter-tropical Africa

Country	Rock type	Fines fraction (%)	Liquid limit (%)	Plastic limit (%)	Plasticity index (%)	HRB/AASHTO classification	References
Cameroon	Basalt	18 – 29 18 - 35	57 – 65 60 – 66	47.7 - 56.4 49.4 -55.1	8.6 – 9.3 8.7 – 11.8	A-2-5 A-2-7	This study
Cameroon	Gneiss	19 - 22	/	/	22 - 25	A-2-7	**[20]**
Cameroon	Micashist	26	55	30	25	A-2-7	**[10]**
Mali	Igneous rock	31 - 33,5 3 - 12	26 – 32 21-26	11.3 – 15.5 12 -14	15-16 9-14	A-2-6 A-2-4	**[9]**
Ivory Coast	Granite	21	48	24	24	A-2-6	**[4]**
Burkina-Faso	Granite	11	22	12	19	A-2-7	**[16]**
Ghana	Igneous rock	15-28	42-51	22-27	20-25	A-2-7	**[7]**
Ghana	Igneous rock	27-33	48-51	19-21	29-30	A-2-7	**[1]**

V. CONCLUSION

The study was based on the evaluation of Bafang gravelly lateritic soils which are the raw material of road construction. As far as geotechnical properties are concerned, the Bafang lateritic soils in general are subdivided in two categories: clayey soil and clayey to loamy sand and gravel. Clayey to loamy sand and gravel soils correspond to gravelly lateritic soils. Based on GIS through IDW interpolation, Boolean model and also constrained by geo-environmental factors (slope gradient, elevation), the gravelly lateritic soils are sparsely distributed in the study area. On 64 km^2 which represent the surface of the study area, only 2.1 km^2 form the concentration zones of gravelly lateritic soils. Therefore, the geotechnical databases on the Bafang lateritic soils in general are established. This will facilitate the preliminary works perform by civil engineering contractors companies before roads building in the Bafang area and will allow them to avoid extend delivery date of the roads works.

The same approach used in this study can be taken to establish the geotechnical databases of lateritic soils in the entire highland of western Cameroon and other inter-tropical highland area.

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