Hydrological, mineralogical and geotechnical characterisation of soils from Douala (coastal, cameroon): potential used in road construction

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ABSTRACT

The life span of pavements in coastal areas is diminutive due to high traffic levels. In this study, soils from different localities (Dibamba, Bekoko and Lendi) in the Douala coastal area were investigated, for their hydrological, mineralogical and geotechnical properties. This is to determine their potential used as raw material in the sub-base or base layer for road construction. Hydrological analysis of data for the past twenty years revealed that the average annual temperature stood at 27.5°C with average precipitation of about 433.1mm. Average relative humidity was 82% throughout the year. XRD/XRF analysis were carried on the different soil samples and revealed quartz ranges from 52 -72%, kaolinite (20-35%); goethite (4-5%), anatase (3-4%) and feldspar (0-4%). The mineralogical content of these soils was similar to silico-aluminous-ferruginous-titanous soils characterized by high silica content (43.52–66.4%), moderate alumina (13.5–31%), low content of Fe2O3 (2.5–3.2%) and TiO2 (1.2–2.02%). The silica/sesquioxide ratio of the various sample ranged from 1:1 to 1:3 indicating that the samples from Bekoko are non-lateritic, those of Dibamba are lateritic while the soils from Lendi are true laterite soils. The laterites are suitable for the sub base layer of road pavements. Specific density of investigated samples ranges between 2.12 and 2.32 g/cm3 a result of low degree of laterization. The percentage of clay in the fine fraction for samples from Bekoko, Dibamba and Lendi stood at 24.5%, 19.0% and 14.9% respectively. These values are lower than 35% which is the standard value recommended for sub-base material by the CEBTP. The Atterberg limits range from 11.50 to 22.4% hence samples from Lendi are the low plasticity while those of Bekoko and Dibamba have a moderate plasticity with low swelling potentials. Soil samples from Dibamba and Bekoko were of the A-7-6 group while Lendi soil samples were of the A-7-5 group which correspond to clayey soils and hence classified as poor materials for road construction according to American Association of State Highway and Transportation Officials (AASHTO) classification. The Unified Soil Classification System (USCS) revealed that, the majority of samples collected in the study area belonged to the SM group (silty sand) except DIB1 and LEN1 samples which pertain to SC group (clayey sand). The average of the maximum dry density (MDD) values stood at 1.9 g/cm3 with an average moisture content of 11% corresponding to the lower limit recommended for the use as sub-base materials. The value of CBR range between 8.6 and 28.2% which correspond to class S4 and can be used as raw material for the foundation layer of low traffic (T1) in the CEBTP standard. If those materials are treated with coarse gravel, cement and/or bitumen, they can be used on sub-base and base layer of high traffic (T2/T3).
of the soil used or located at the bottom of the structure (house, road) is the main cause of failure of buildings and road pavements.

Then to reduce or explain this behaviour, those properties shall be known or improved upon (Garg, 2009). The tropical zone is characterised by the permanent rainfall and temperature variation which weather the rock and produce the high thickness of laterite in any country located at that zone (Garg 2009).

Regarding their wide spread, many authors (Hyoumbi et al., 2018, Nzabakurikiza et al. (2017); Onana et al. (2017); ojo et al., 2003, Sikali et al. (1986), Gidigasu 1983) have investigated their properties and recommend their used for road construction, foundation, earth dams and ecological brick for the house construction. Therefore, Lemounga et al. (2011) said that the important ore deposit of laterite in any area constitute the economical used in the civil engineering.

In Cameroon, the laterites cover around 70% of country (Mbumbia et al., 2000). Depending on their class (laterite gravel, laterite clays and laterite shale) they are respectively used in road construction and in the production of earth brick.

The rapid deterioration of roads in the city of Douala is due to recurrent flooding and the poor quality of materials used for construction works (Sandjong et al., 2020). Indeed, water is responsible for premature degradation of pavements as it accelerates or causes degradation such as the rise of fines rutting cracking and localised defects (potholes). This could be due to the proximity to groundwater. High water content in soil reduces the bearing capacity hence result to deformation problems and the appearance of cracks on road pavement. The permanent deformations of untreated materials (untreated gravel bedding) are caused by the variation of the water content of these materials which is one of the main ways of deterioration of flexible pavements (Allou et al., 2007).

Generally, they are of good to fair quality as raw materials used in both building and road construction. In civil engineering, particularly in road pavement, only the geotechnical properties are used to justify the quality of raw material used (Millogo et al., 2008). In the tropical zone where climate change is a reality, Millogo et al. (2008); Mahalinger et al.(1997) purposed to add on geotechnical properties, the mineralogical and chemical characterization were carried out to understand more the behaviour of the material before used. The Coastal zone is characterized by rain most of the year hence the soils in this area have high water content. This research proposes to combine geotechnical, chemical, mineralogical and hydrological analysis to improve on the data on soils from Wouri area. This research paper intended to evaluate the potential used of the soils from coastal zone in road layer and contribute to the data base for pavement design in the future.

2. Materials and methods

2.1. Sampling

Five samples were taken from each quarry at Dibamba (DIB1, DIB2, DIB3, DIB4, and DIB5), Lendi (LEN1, LEN2, LEN3, LEN4, LENS) and Bekoko (BEK1, BEK2, BEK3, BEK4, BEK5) in the Wouri sub-division. These samples belong to the Mio Pliocene geological era (Figure 1) and are characterised by sand and clays with miogypsins interstratiﬁed with aged basalt Burdigalien (Mbesse 2013). The soil proﬁle in the study area is marked predominantly by coarse sand at the base and ﬁne sand at the top, alternating with bariolate clays and sometimes intercalated by basalts.

At each quarry, eighty kilograms (80 kg) of disturbed sample was collected at each point and stored in the polystyrene bags in other to maintain their natural properties. Then, they weredried at room temperature during two weeks and geotechnical properties were determined.

Meteorological data (Precipitation and temperature) of two decades (2000–2020) was collected at the weather stations of the Regional Delegation for Transportation of Douala.

2.2. Methods

2.2.1. Hydrological properties

2.2.1.1. Rainfall and temperature. The data of twenty years has been computed with Microsoft excel to obtain a histogram which combines the variation of rainfall and temperature.

Figure 1. Geological map of the study area.
2.2.1.2. Evapotranspiration. Real evapotranspiration (REE) is the quantity of rain loss through evaporation and transpiration of plants. REE is the measure of water transfer from the subsoil to the atmosphere. It is calculated in tropical Africa by the Turc formula (1) which stipulates that:

\[
\text{REE} = \frac{P}{(0.9 + \left(\frac{P^2}{L^2}\right)^{1/3})}
\]

(1)

Where: \(L = 300 + 25T + 0.05T^3\), \(P\) and \(T\) represent rainfall and the thermal average respectively for the region. The meteorological data showed that \(P = 3706.5\) mm and \(T = 27.5\) °C

2.2.1.3. Runoff. The runoff was calculated by taking into consideration the annual contributions of the two main rivers in the region (Wouri and Dibamba). The total runoff thus corresponds to the sum of the runoff of each river.

This runoff was calculated using formula (2):

\[
R = \frac{Q \times t}{S}
\]

(2)

Where

- \(Q\) = average annual flow;
- \(t\) = duration of flow over one year
- \(S\) = catchment area.

According to the work of Mbida (2004), the annual contribution of river Wouri is \(10 \times 10^8\) m³, i.e. a flow of 317.098 m³/s; while that of the Dibamba is \(2 \times 10^8\) m³, i.e. a flow of 63.42 m³/s.

2.2.1.4. Infiltration. Infiltration is the proportion of water from precipitation that percolates into the soil to build up the groundwater reserves responsible for the formation of the groundwater table. This parameter is vital as it is detrimental to the pavement. It is obtained from the water balance relation: \(E = S\).

\(E\) corresponds to precipitation inputs (\(P\)) and \(S\), output represented here by evaporation (\(ET\)), plant transpiration (\(Tp\)), infiltration (\(I\)) and total runoff (\(R_t\)). The infiltration is given by Eq. (3).

Thus, \(P = ET + Tp + I + Rt\).

hence \(I = P - (ET + Tp + Rt)\) (3)

2.2.1.5. Mineralogical properties. Mineralogical analysis was performed by using X-ray diffraction of diffractometer Bruker Advance D8 (copper Kα1 radiation, \(\lambda = 1.5418\) Å, \(V = 40\) kV, \(I = 30\) mA) at the AGES (Argiles, Géochimie et environnement sédimentaire) laboratory of the University of Liege in Belgium according to the methodology of Moore et al. (1989). The average sample of each area (BEK, DIB and LEN) have been sieve at mesh 100 μm. The diffractometer Bruker Advance D8 (copper Kα1 radiation, \(\lambda = 1.5418\) Å, \(V = 40\) kV, \(I = 30\) mA) the Eva software have been used to identify the different types of minerals present in the studied sample. The content of minerals found has been obtained by using the matrix calculation technique developed by Njowpouo (1985) and Yvon et al. (1982) according to the relation (4). Which consist to use the proportion of oxide given to XRF result to obtain the good content of mineral in the sample.

\[
T(a) = \sum_{i=1}^n M_i \cdot p_i(a)
\]

(4)

Where

- \(T(a)\) = Mass percentage of the oxide of the chemical element (\(a\)) in the sample
- \(M_i\) = Mass percentage of mineral \(i\) in the material studied; 
- \(P_i(a)\) = Mass proportion of the oxide of the element (\(a\)) in the mineral \(i\) deduced from the ideal formula attributed to this mineral \(i\).

2.2.1.6. Geochemical properties. The X-ray fluorescence spectrometer has been used to determine the geochemical properties of the average sample of each area (BEK, DIB and LEN) at the petrology laboratory of the University of Liege. The mass of 0.34 mg of the sample (0.34 mg) has been previously calcified at 1000 °C then mixed with KBr (3.74 mg), BrLi (0.0002 mg) and fired to form pellets. The Bruker S8 Tiger (4 kW) was recorded the major oxides in each sample.

2.2.1.7. Geotechnical properties. The French test specifications was used to obtain the engineering properties of soils notably the state parameters (water content, degree of saturation, density of solid grains, absolute density, apparent density, void ratio, porosity), nature parameters (granulometry analysis, Atterberg limits) and mechanical parameters (Modified Proctor and CBR test).

The AFNOR Standard (1991) has been used to determine the specific densities of the materials. The grain size analysis was determined by dry sieving and sedimentation according to AFNOR (1990c; 1996, 1992) respectively. The Casagrande method was used to determine the liquid limit and plastic limit. The difference between the liquid limit and plastic limit give us the plasticity index (\(PL = WL-PL\)). These measurements were obtained according to the French standard (AFNOR, 1993).

2.2.1.8. Mechanical properties. The modified Proctor test was carried out in accordance with AFNOR (1999) standards. The curve of modified Proctor permit to determine the optimum moisture content (OMC) and obtain the maximum dry density (MDD). The MDD is a good indicator of the compactness and bearing capacity of the soil after sufficient compaction.

The Californian Bearing ration (CBR) was determined according to the French Norm (AFNOR 1997). It measures the shear strength of a soil and the swelling of the soil when it is immersed in water for 4 days. This permits the calculation of the bearing capacity of the soil, by estimating its resistance to punching.

3. Results and discussions

3.1. Hydrological characteristics

3.1.1. Precipitation

The variation in rainfall data (Table 1) illustrates two main seasons (Figure 2). A major rainy season lasting about 09 months (March to November) and a dry season lasting 03 months (December to February). Examination of the distribution of monthly rainfall in the locality indicates that the annual average rainfall is 433.1 mm with the maximum value in August (707.1 mm) and the minimum in January (32.8 mm). These meteorological data over a period of 20 years (2000–2020) can be summarised as a humid equatorial coastal climate influenced by the sea and the proximity of Mount Cameroon, and marked by permanent rainfall throughout the year.

3.1.2. Temperature

The average temperature is 27.3 °C. August is the coldest month with an average temperature of 25.5 °C, while February register the highest temperature with a monthly average value of 28.9 °C (Table 1 and Figure 2).

3.2. Relative humidity

The air is almost constantly saturated with humidity. Indeed, the average monthly relative humidity in Douala for a period of 20 years (2000–2020) is around 82%. The average monthly values vary between
78% and 88% during the rainy season and between 77% and 81% during the dry season (Table 1 and Figure 3).

3.2.1. Evaporation
The average values of evaporation were highly lower in the rainy season than the annual rainfall. This favor aquifer recharges (Table 1 and Figure 4). In the dry season, the opposite phenomenon occurs, resulting in a drop in the static level and the drying out of the water table, which leads to excessive shrinkage of the materials used to reinforce the road layers. The periodic annual average value of evaporation was: ET = 1288.5 mm/year. This value represents 34.76% of precipitation.

3.2.2. Infiltration rate
The infiltration rate stands at 11.88% of rainfall (Table 2). This considerable proportion can be explained by the fairly intense rainfall and high permeability of the geological formations in the study area.

3.2.3. Runoff rate
The average annual runoff rate is 39.57% (Table 2). This value is higher than that of infiltration, hence, explains the permanent saturation of the soil in the rainy season, this leads to recurrent flooding (Figure 5) and an intense evapotranspiration phenomenon (48.8%) in the dry season. The phenomenon of extreme evapotranspiration leads to the desiccation of soils with a strong shrinkage that weakens the superstructure of the roads in the face of the intense daily traffic in the economic capital of Cameroon.

3.3. Mineralogical and chemical analysis

3.3.1. Mineralogy
Figure 6 shows the different spectral come out of X-ray diffraction in the raw materials. Those X-ray diffraction spectra reveal great similarity in the composition of the mineral phases although at different proportions (Table 3). The Bekoko samples (BEK) contains 20% kaolinite, 72% quartz, 5% goethite, 3% anatase and 0% feldspar. The Dibamba samples (DIB) consist of 35% kaolinite, 52% quartz, 5% goethite, 4%...
anatase and 4% feldspar. Lendi samples (LEN) is composed by 29% kaolinite, 61% quartz, 4% goethite, 3% anatase and 3% feldspar. The dominant minerals in all three samples are kaolinite and quartz. However, it is worth noting that the Dibamba samples are rich in kaolinite than samples from Lendi and Bekoko. On the other hand, the Bekoko samples present the higher quartz content.

The abundance of these minerals phases is in relation with the major oxides like SiO$_2$, Al$_2$O$_3$, Fe$_2$O$_3$ and TiO$_2$ which are the main characteristic of lateritic soil in tropical zone (Lemougna et al., 2011; Onana, 2010; Ekodeck, 1984).

Peaks from the diffractogram shows high proportion of quartz (52–72%) a mineral very resistant to weathering. Relatively weak peaks of kaolinite (20–35%) can be observed.

The action of the permanent humidity ratio around 82% which increase the formation of the kaolinite during the meteoric weathering process on the primary minerals like feldspar in the tropical zone (Ngueumdjo et al., 2020; Legros, 2013).

Table 2. Annual water balance in the Douala sub-basin.

| Component of report | Quantity (mm) | Percentage |
|---------------------|---------------|------------|
| Precipitations (P)  | 3706.70       | 100.00 %   |
| ETR                 | 1799.50       | 48.55 %    |
| Runoff rate (R)     | 1466.67       | 39.57 %    |
| Infiltration (I)     | 440.33        | 11.88 %    |
| E – S (Annual report)| 0.00          | 0.00 %     |

Table 3. Proportion of minerals in samples from the study area.

|          | Kaolinite | Quartz | Goethite | Anatase | Feldspar |
|----------|-----------|--------|----------|---------|----------|
| BEK      | 20%       | 72%    | 5%       | 3%      | 0%       |
| DIB      | 35%       | 52%    | 5%       | 4%      | 4%       |
| LEN      | 29%       | 61%    | 4%       | 3%      | 3%       |

Figure 4. Average monthly evaporation in the study area (2000–2020).

Figure 5. Map of flood-prone areas in the city of Douala defined from the topography (Zogning et al., 2013).
The goethite (4–5%) and anatase (3–4%) content are relatively low and reflects the saturation (reducing) conditions favourable to the formation of those minerals according to the permanent humidity ratio (82%) every month during twenty years.

The cracking observed in the residual soil during compaction may be due to the action of the goethite or iron oxides as the cementous agent which making the structure relatively brittle (Kamtchueng et al., 2015; Indraratna et al. 1991). The mineralogical composition influences the mechanical behaviour of the material use in pavement. The high content of kaolinite (20–35%) and anatase (3–4%) reduce the bearing capacity of soil materials (Issiakou 2016). While the occurrence of quartz (52–72%) improves the bearing capacity of soil materials used in pavement layers (Millogo et al., 2008).

The mineralogical composition of the various samples in the Wouri area reveal that samples from Bekoko would have a better bearing capacity than samples from Lendi and Dibamba.

### 3.3.2. Chemistry

The results of chemical analysis (Table 4) show the silico-alumina-ferruginous-titania composition which is illustrated by the large amount of SiO2 (75.0–79.8%) with relatively high content of Al2O3 (11.5–15.0%) and low content of Fe2O3 (2.5–3.2%) and TiO2 (1.2–2.02%). The alkaline oxides (Na2O + K2O) and alkaline earths oxides (CaO + MgO) contents are very low (0.0–0.05%). The low concentrations in alkaline and alkaline earths oxides are attributed to the strong hydrolysis alongside heavy precipitation, as shown by the Runoff analysis increasing up to 3706.70 mm (Table 1). However, in other parts of the tropics e.g. sandstone from Sapouy-Burkina Faso show high values of alkaline and alkaline earth oxides between 0.05 – 4.24% (Millogo et al., 2008).

The LOI range from 4.3 to 6.4 %. This range is low and attributed to the occurrence of kaolinite identified by X-ray diffraction analysis. The LOI found on these samples is lower than the range 10–30%, found in typical lateritic soils which contain kaolinite (Akpodokje et al., 1994; Nwaiwu et al., 2006; Nzabakurikiza et al., 2017).

| Locality | ld_sample | ρh | ρs | ρde | n | Sr |
|----------|-----------|----|----|------|---|----|
| Bekoko   | BEK 1     | 2.66 | 2.19 | 1.90 | 0.40 | 28.60 | 8.05 |
|          | BEK 2     | 2.59 | 2.22 | 1.87 | 0.43 | 30.52 | 7.22 |
|          | BEK 3     | 2.53 | 2.17 | 1.79 | 0.41 | 29.32 | 7.43 |
|          | BEK 4     | 2.67 | 2.21 | 1.96 | 0.41 | 26.60 | 7.98 |
|          | BEK 5     | 2.68 | 2.32 | 1.95 | 0.37 | 27.43 | 8.66 |
| Mean     |           | 2.63 | 2.22 | 1.89 | 0.41 | 28.49 | 7.87 |
| SD       |           | 0.06 | 0.06 | 0.07 | 0.01 | 1.54  | 0.57 |
| Dibamba  | DIB 1     | 2.72 | 2.23 | 1.92 | 0.42 | 29.44 | 11.38 |
|          | DIB 2     | 2.78 | 2.17 | 1.82 | 0.53 | 34.53 | 9.17 |
|          | DIB 3     | 2.69 | 2.12 | 1.98 | 0.36 | 26.35 | 13.23 |
|          | DIB 4     | 2.81 | 2.23 | 1.91 | 0.47 | 32.02 | 10.39 |
|          | DIB 5     | 2.71 | 2.19 | 1.97 | 0.37 | 27.26 | 12.71 |
| Mean     |           | 2.74 | 2.19 | 1.92 | 0.43 | 29.92 | 11.38 |
| SD       |           | 0.05 | 0.05 | 0.06 | 0.07 | 3.38  | 1.66 |
| Lendi    | LEN 1     | 2.76 | 2.20 | 1.91 | 0.45 | 30.83 | 11.97 |
|          | LEN 2     | 2.89 | 2.12 | 1.96 | 0.48 | 32.35 | 11.42 |
|          | LEN 3     | 2.83 | 2.26 | 1.89 | 0.50 | 33.39 | 11.41 |
|          | LEN 4     | 2.77 | 2.19 | 1.78 | 0.56 | 33.88 | 9.28  |
|          | LEN 5     | 2.88 | 2.24 | 1.91 | 0.50 | 33.51 | 11.11 |
| Mean     |           | 2.83 | 2.20 | 1.89 | 0.50 | 32.79 | 11.04 |
| SD       |           | 0.06 | 0.05 | 0.07 | 0.04 | 1.24  | 1.03 |

### Table 4. Proportion of major oxides in the samples from the study area.

|         | SiO2 | TiO2 | Al2O3 | Fe2O3 | MnO | MgO | CaO | Na2O | K2O | P2O5 | SO3 | LOI | SiO2/Al2O3 | SiO2/(Fe2O3+Al2O3) |
|---------|------|------|-------|-------|-----|-----|-----|------|-----|------|-----|-----|------------|-------------------|
| DIB     | 75.00| 1.20 | 15.02 | 2.50  | 0.01| 0.00| 0.05| 0.00 | 0.05| 0.05 | 0.00| 6.12| 4.9        | 4.28               |
| BEK     | 75.09| 1.25 | 13.92 | 3.24  | 0.02| 0.00| 0.02| 0.00 | 0.02| 0.06 | 0.00| 6.38| 5.39       | 4.37               |
| LEN     | 79.79| 0.82 | 11.53 | 2.80  | 0.01| 0.00| 0.02| 0.00 | 0.11| 0.03 | 0.00| 4.90| 6.92       | 5.56               |
Table 6. Geotechnical and mechanical characteristic of the laterite from the study area.

| Particle size distribution | DIB 1 | DIB 2 | DIB 3 | DIB 4 | DIB 5 | BEK 1 | BEK 2 | BEK 3 | BEK 4 | BEK 5 | LEN 1 | LEN 2 | LEN 3 | LEN 4 | LEN 5 | Statistics |
|----------------------------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| Mean | SD   | Mean | SD   | Mean | SD   | Mean | SD   | Mean | SD   | Mean | SD   | Mean | SD   | Mean | SD   | Mean | SD   |
| <2mm | 36.0 | 37.5 | 37.4 | 37.7 | 37.6 | 37.2 | 2.0  | 37.8 | 31.3 | 37.8 | 32.6 | 37.7 | 35.4 | 41.9 | 35.9 | 35.8 | 36.8 |
| >0.425 mm | 3.0 | 37.9 | 37.4 | 37.0 | 30.1 | 0.5 | 30.4 | 33.5 | 30.3 | 33.6 | 29.6 | 31.5 | 14.3 | 30.3 | 30.2 | 29.0 | 29.0 |
| <80 μm | 20.5 | 20.0 | 20.1 | 20.0 | 19.8 | 20.1 | 0.3 | 19.7 | 21.8 | 19.7 | 21.0 | 19.3 | 20.3 | 4.7 | 20.9 | 21.0 | 20.9 | 21.1 |
| <2 μm (Clay) | 19.9 | 18.6 | 18.6 | 19.7 | 18.4 | 19.0 | 1.9 | 26.0 | 22.7 | 26.3 | 21.6 | 25.8 | 24.5 | 19.3 | 15.4 | 15.1 | 14.8 | 14.6 |
| Silt | 41.3 | 42.0 | 41.9 | 38.6 | 42.3 | 41.2 | 9.3 | 44.4 | 38.4 | 44.6 | 40.5 | 45.0 | 42.6 | 35.0 | 27.7 | 27.0 | 26.9 | 27.3 |
| Sand | 21.1 | 19.6 | 19.8 | 20.9 | 19.5 | 20.2 | 2.1 | 0.0 | 13.3 | 0.0 | 12.5 | 0.0 | 5.2 | 201.3 | 42.2 | 41.4 | 42.0 | 41.7 |
| Gravel | 21.1 | 19.6 | 19.8 | 20.9 | 19.5 | 20.2 | 2.1 | 0.0 | 13.3 | 0.0 | 12.5 | 0.0 | 5.2 | 201.3 | 42.2 | 41.4 | 42.0 | 41.7 |

Atterberg Limits

| LL | 49.0 | 48.7 | 50.2 | 49.8 | 51.3 | 49.8 | 4.3 | 44.5 | 45.0 | 46.9 | 44.7 | 45.3 | 45.3 | 3.5 | 42.8 | 42.4 | 41.0 | 42.9 |
| PL | 26.7 | 27.2 | 27.2 | 28.8 | 30.7 | 28.1 | 10.8 | 23.1 | 23.2 | 24.4 | 21.1 | 22.3 | 22.8 | 6.0 | 31.3 | 30.9 | 29.4 | 31.2 | 32.0 |
| PI | 22.3 | 21.5 | 23.0 | 21.0 | 20.6 | 21.7 | 3.8 | 21.4 | 21.8 | 22.5 | 23.6 | 23.0 | 22.4 | 3.0 | 11.5 | 11.5 | 11.6 | 11.7 | 11.2 |
| CI | 1.4 | 1.5 | 1.4 | 1.5 | 1.6 | 1.5 | 0.0 | 1.5 | 1.5 | 1.5 | 1.4 | 1.4 | 1.5 | 0.02 | 2.0 | 2.0 | 1.8 | 2.1 | 2.1 |
| GI | 6 | 4 | 5 | 5 | 5 | 0.71 | 6 | 5 | 5 | 6 | 6 | 5.20 | 0.84 | 2 | 2 | 2 | 2 | 2 | 2 |

Derived Parameters

| Grading modulus (Gm) | 2.13 | 2.13 | 2.13 | 2.12 | 2.12 | 2.12 | 0.0 | 2.12 | 2.13 | 2.12 | 2.13 | 2.1 | 0.00 | 2.13 | 2.13 | 2.13 | 2.13 | 2.13 |
| Activity ration (Ac) | 1.1 | 1.2 | 1.2 | 1.1 | 1.1 | 1.0 | 0.9 | 1.1 | 0.9 | 0.9 | 0.9 | 0.0 | 0.7 | 0.8 | 0.8 | 0.8 | 0.8 | 0.77 |
| plasticity modulus (Pm) | 683.9 | 643.0 | 686.8 | 625.6 | 620.6 | 651.9 | 3974.4 | 652.4 | 791.2 | 680.4 | 766.9 | 11966.0 | 349.9 | 347.7 | 350.4 | 338.5 | 324.9 | 342.9 |
| plasticity product (Pp) | 456.9 | 429.3 | 461.5 | 419.7 | 408.6 | 435.2 | 2150.4 | 421.4 | 475.4 | 442.3 | 496.0 | 442.3 | 3541.7 | 240.3 | 241.0 | 242.9 | 246.4 | 238.5 |
| Swelling potential (εs) | 0.010 | 0.010 | 0.011 | 0.009 | 0.008 | 0.010 | 0.0 | 0.010 | 0.010 | 0.011 | 0.012 | 0.011 | 0.0 | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 |

Classification

| AASHTO | A7-6 | A7-6 | A7-6 | A7-6 | A7-6 | A7-6 | A7-6 | A7-6 | A7-6 | A7-6 | A7-5 | A7-5 | A7-5 | A7-5 | A7-6 | A7-5 | A7-6 |
| USCS | SC | SM | SM | SM | SM | SM | SM | SM | SM | SM | SM | SM | SM | SM | SM | SM | SM |
| GTR | A2 | A2 | A2 | A2 | A2 | A2 | A2 | A2 | A2 | A2 | A2 | A2 | A2 | A2 | A2 | A2 | A2 | A2 |

Modified Proctor

| MDD | 1.9 | 1.820 | 2.0 | 1.9 | 1.971 | 1.9 | 0.0 | 1.9 | 1.9 | 1.9 | 2.0 | 1.9 | 1.9 | 0.0 | 1.9 | 1.9 | 1.9 | 0.0 |
| OMC (%) | 12.5 | 12.8 | 9.0 | 10.5 | 10.9 | 11.1 | 9.7 | 12.5 | 12.8 | 9.0 | 10.5 | 10.9 | 11.1 | 9.7 | 12.8 | 7.4 | 9.4 | 9.9 |
| CBR | 17.5 | 17.4 | 17.6 | 17.4 | 17.5 | 17.5 | 0.0 | 12.1 | 12.0 | 12.2 | 12.1 | 12.2 | 12.1 | 0.0 | 19.3 | 18.9 | 20.2 | 18.7 |
| NMC (%) | 30.0 | 27.6 | 28.0 | 27.0 | 27.5 | 28.2 | 5.1 | 14.2 | 18.8 | 17.0 | 21.5 | 18.8 | 18.1 | 29.0 | 9.6 | 9.3 | 9.3 | 7.1 |

Gm = \left(\% \text{< 2 mm} + \% \text{< 425μm} + \% \text{< 75 μm}\right)/100; Ac=PI/(%< 2μm); Pm= PI* Percentage passing 425μm test sieve (Charman 1988); Pp = PI* Percentage passing 75 μm test sieve (Charman 1988); es = 1 × 10−5PI/2.4 (Millogo et al., 2008); DIB: Dibamba; BEK: Bekoko; LEN: Lendi.
The silica/alumina ratio ranges from 4.9 to 6.9. This indicates the presence of free silica in the Bekoko, Dibamba and Lendi samples, as the particle size analysis shows an average sand content of over 40%. Rossiter (2004) has used the silica sesquioxide (S–S) ratio SiO$_2$/Fe$_2$O$_3$ + Al$_2$O$_3$ to classify the laterite by their degree of laterization. He concluded that, S–S > 2; 1.33 < S–S < 2 and S–S < 1.33 corresponds respectively to non-lateritic soils, laterite soils and true laterite soils.

Figure 7. Particle size distribution of soil samples.

Figure 8. Position of the studied materials in the Casagrande plasticity chart.
The soil samples from Bekoko have S–S ratio (3.1) greater than 2 suggesting that they are "non-lateritic soils". Those of Dibamba are lateritic soils with a characteristic S–S value = 1.5 while the Lendi samples are true laterite (S–S = 1.1). Also according to the brazilian specification (DNIT 2007), the S–S value of Bekoko samples (3.1) greater than 2 suggest that, these materials can be used for sub-base layers.

However, samples from all these areas (Bekoko, Lendi and Dibamba) are classified as non-lateritic soils (Paige-Green et al., 2015). This is because their sesquioxide ratio range from 14.3 to 17.5 % and lower than recommended proportion of 20–49 % (Tockol et al., 1994).

3.4. Geotechnical characterization

3.4.1. Status parameters of raw materials

Table 5 present the results of the status settings. The humid density of the raw materials analyses is close to 2.53 and 2.89 g/cm³. The average humid density of samples from Bekoko, Dibamba and Lendi are 2.6; 2.74 and 2.8 g/cm³ respectively. The Lendi sample has the highest value of humid density. It is worth nothing that humid density varies with porosity ratio an increase in porosity of the materials means the material is susceptible to be filled with water.

The specific density of the samples varies between 2.12 and 2.32 g/cm³. The sample from Bekoko have the highest specific gravity value (average of 2.22 g/cm³) while the Dibamba samples have the lowest value (average of 2.19 g/cm³). According to the result obtained in other zone in Cameroon, those specific density values are lower than those observed on lateritic gravelly soils (2.66–2.68 g/cm³) from Bafang (Hyoumbi et al., 2018); lateritic soils from Mfou (2.38–2.83 g/cm³) by Kamthuen et al. (2015) and lateritic gravelly soils from Eastern Cameroon (2.73–2.90 g/cm³) by Nzabukurikiza et al. (2017); Onana et al. (2017).

The specific density for samples in the studied area reveal that, they are laterite soils with low degree of laterization (less dense) which may link to the mineralogical and chemical composition (Que et al., 2008; Ramamurthy et al. (2005). The composition attest to the low specific density compared to other lateritic soils around the country with low concentrations of heavy oxides like goethite (4–5%), alumina oxide (11.53–15.02%), iron oxide (2.50–3.24%) and highest concentration of kaolinite (20–35%) a light oxide.

The average void ratio of each sample increases gradually with the porosity ratio (Table 5). The low void ratio (0.4) and the porosity (28.5%) was found in the Bekoko sample. This is attributed to the heterogeneity of grain size (both fine and coarse grained) where the fine particles filled the space between coarse grains. High void ratio (0.5) and the porosity (32.7%) are seen in samples from Lendi. This is explained by a natural moisture content of 19.3% indication that the pore spaces are filled with water. The bulk density of analyzed samples ranges from 1.82 to 1.96 g/cm³. The Bekoko samples have an average apparent density of 1.89 g/cm³, Lendi and Dibamba samples have the highest value 1.92 g/cm³.

Table 7. Compliance of laterite soil of Douala to road pavement standards for tropical countries (CEBTP, 1984).

| Engineering parameters | Base materials | Sub-base materials | Samples |
|------------------------|---------------|-------------------|---------|
| Liquid limit (LL) (%)  | 35 max        | 60 max            | 45.3    |
| Plasticity ratio (PI %)| 15 max        | 30 max            | 22.8    |
| Swelling potentials    | 0.3 Max       | 1                 | 0.01    |
| Grain size distribution (%) |        |                   | 0.01    |
| 20 mm                  | 60-100        | 75-700            | 80      |
| 10 mm                  | 35-90         | 58-100            | 65      |
| 5 mm                   | 20-75         | 40-78             | 55.4    |
| 2 mm                   | 12.50         | 28-65             | 35.4    |
| 0.080 mm               | 4.20          | 5-35              | 20.3    |
| Maximum dry density    | 2.00 min      | 1.9 min           | 1.9     |
| CBR at 95% of MDD (%)  | 80 min        | 30 min            | 18.1    |

Figure 9. Dry density versus water content curve.
land (Diop et al., 2014) estimated at 82% over a period of 20 years. This water content indicates or predicts accelerated degradation if those natural materials which are used as a pavement layers without stabilization.

### 3.4.2. Grain size distribution and Atterberg limits

Naresh et al. (2006) highlights the importance of particle size distribution in the design of structures and also to appreciate the compaction capacity of soils (Tse et al., 2016). The recorded grain size data from the samples of Bekoko, Dibamba and Lendi localities are summarise in Table 6 and graphically illustrated by Figure 7.

The samples of Dibamba are composed of an average of 20.2% gravel, 41.2% sand, 19.6% silt and 19% clay fractions. The average percentage of 5.2% of gravel, 42.6% sand, 27.8% silt and 24.5% clay have been found in the sample from the Bekoko. The samples from Lendi locality have showed an average amount of 41.9%; 27.2%; 16% and 14.9% respectively for gravel, sand, silt and clay.

The analysis of the particle size curves reveals that coarse sand is the most represented granular class in the Bekoko (42.6%) and Dibamba samples (41.2%). Gravel (41.9%) is the most represented class in the Lendi samples. To characterise the granularity of the soils, they are usually divided into four groups. The first group corresponds to the size range from 2 mm to 0.1 μm, the second group belong to the size vary form 0.4 to 80 μm, the third group is the size which close from 80 to 0.1 μm and the fourth group is the grain size lower than 2 μm according to Sikali et al. (1986). The percentage of the second group fraction (ø < 0.425 mm) varies between 20.1 and 21%. The particle size percentage distribution for the fourth group (clays: ø < 2μm) varies from 24.5% for the Bekoko, 19% for the Dibamba site and 14.9 % for the samples from Lendi.

The low fine particle content and high sand concentrations in the samples indicate a low water retention capacity, low plasticity and high dry density during compaction of these materials. This is because a high proportion of fine particles leads to a reduction in density, maximum strength and show the evidence of the material to subsidence by seepage (Garg 2009).

The average percentage of fine particles (<80 μm) ranges from 20.1% (Dibamba sample) to 21.03% (Lendi sample). These percentages are less than recommended value by the CEBTP (1984) for sub-base materials samples which stands at 35% (Table 6).

Specific samples from the Bekoko site and the Dibamba site (DIB5, BEK1, BEK3) are closed to the particle size distribution envelope specification (<20% of fines) for the materials used in the base layer of the road (CEBTP 1984).

The Atterberg limits results are given in Table 6. From Table 6, the Dibamba, Bekoko and Lendi samples contain an average water content of 49.8, 45.25 and 42.44% respectively without sinking under their own weight. Furthermore, they can only undergo plastic deformation with water contents below 28.12%, 22.80%, and 30.94% respectively.

These two parameters give an average plasticity index of 21.68, 22.45 and 11.50% for the Dibamba, Bekoko and Lendi soils respectively. The plotting of the samples on the plasticity diagram of Casagrande (Figure 8) shows that, Lendi samples are less cohesive soils while the Bekoko and Dibamba samples are low plastic clays.

The results obtained are within the range of the liquidity limit (42–89%) and plasticity index (21–55%) obtained by (Ramchuen et al. 2015; Pilot et al., 1970) in the humid zone of the centre region of Cameroon. However, the plasticity index of the Dibamba and Bekoko samples are close to those obtained in Côte d’Ivoire (PI = 22%) on laterite (Bohi 2008) whereas that of the Lendi samples is close to the plasticity index (PI = 11%) of laterite samples from Burkina Faso (Millogo et al., 2008).

The plasticity specification is given in Table 8. The plasticity index of material used in the sub-base layer of the road pavement should range from 20 to 30% and less than 15% for the use in the base layer (CEBTP, 1984). Otherwise, the Bekoko and Dibamba samples with a plasticity index respectively 22.4% and 21.7% can be used as sub-base layers while the Lendi samples (plasticity index: 11.5%) can be used as base layers (Table 8).

### Table 8. Use of materials according to their CBR (DEGN, 1987).

| Classe de CBR Use in road construction | S1: 0 < CBR < 5 Not suitable for road construction | S2: 5 < CBR < 10 Sub-base layer | S3: 10 < CBR < 15 Sub-base layer and backfill | S4: 15 < CBR < 30 Sub-base layer for a Traffic T1 | S5: 30 < CBR < 60 Sub-base layer for Traffic T2/T3 and base layer for traffic T1 | S6: CBR > 120 Base layer traffic T3 |
|----------------------------------------|--------------------------------------------------|---------------------------------|---------------------------------------------|----------------------------------|---------------------------------|---------------------------------|

Figure 10. Dry density versus CBR curve.
3.4.3. Classification

The combination of Atterberg’s limit result with the grain size analysis allowed the classification of Dibamba, Bekoko soil samples in the A-7-6 and Lendi soil samples in the A-7-5 group of the American Association of State Highway and Transportation Officials (AASHTO) classification. This means that, our samples are clayey soils.

According to the “Guide des Terrassements Routiers” (GTR) classification, the sample of Dibamba and Bekoko belong to A2 group (fine sand clayey) while the samples of Lendi close to A1 (weak plastic silt or fine sand without pollution).

The unified soil classification system (USCS) shows that, the majority of samples collected in the study area belong to SM group (silty sand) except DIB1 and LEN1 samples which plot in the SC group (clayey sand).

3.4.4. Derived parameters

To evaluate the performance of the whole materials according to their plasticity, they often used the derived parameters (Table 6) to quantify the effective contribution regarding the proportion of fines in the materials (Charman, 1988).

The use of derived parameters are not specified in any standard, then Charman (1988) suggested some criterion like grading modulus, plasticity modulus, swelling ratio and activity to validated the materials for sub-base and base layers of paved and unpaved road in the tropical zone. The mean value of the grading modulus (Gm) is 2.1 for the samples from Dibamba, Bekoko, Lendi. This average value (2.1) is greater than 1.5 and hence indicates that, these materials can be potentially used in sub-base layers and base layer for the lower traffic roads (Charman, 1988).

The activity ratio (Ac) value varies from 0.7 to 1.2 with an average of 1.1, 0.9 and 0.7 for the samples from Dibamba, Bekoko and Lendi respectively. Following the classification of Skempton based on the activity of fine particle, the samples of the study areas are of normal activity (0.75 < Ac < 1.5). The normal activity of the sample is due to the presence of kaolinite (20–35%) which is less active (0.4). The activity of the natural soils is influenced by many factors like mineralogy and size of the particles. That is why Pilot et al. (1970) said that, the grains size greater than two micrometres plays an important role as does the organic matter content. The comparison of our activity result to those found on ferruginous gravels of the North West of Nigeria (0.35–0.87) has shown to be higher value due to the high value of plasticity of our sample (11.5–22.4) contrary to the lower value of plasticity ferruginos gravel (5.56–8.37) according to Nwaiwu et al. (2006).

The Dibamba; Bekoko and Lendi sample have illustrated average value of the plasticity modulus (Pm) respectively of 65.1, 680.4 and 342.09. For all types of roads in equatorial zone, the plasticity modulus (Pm) must be less than or equal to 150 for the base layers of urban roads, less than 30% (Table 7). They vary between 14.2% and 21.5% for the Bekoko soils samples, 27 and 30 for the Dibamba soil samples and 7.1 and 9.6% for the Lendi samples, i.e. an average of 18.6, 28.2 and 8.6% respectively (Figure 10). The low value of the bearing capacity of those samples is due to permanent widespread humidity (82%) in relation with 39.57% of Runoff rate after the infiltration of 11% of the total rainfall in the littoral zone.

Only sample DIB1 (CBR = 30%) is close to the lower limit of CEBTP standard for materials used in sub-base layer (Table 7). The Dibamba, Bekoko and Lendi samples are of poor quality which does not permit them to be used as raw materials in road pavement.

These natural materials have low bearing capacity (CEBTP 1984). Based on the CBR at 95% of the average dry density value (1.9 g/cm³), these materials are of S4 class and can therefore be used as a sub-base for T1 traffic (Table 8).

However, due to its relatively high plasticity index, liquid limit and low swelling potential (Table 6), these soils need mechanical, physical and/or chemical amelioration with hydraulic binders such as quicklime, bitumen and/or cement prior to usage as base materials for road construction.

4. Conclusion

The main point of this work was to characterise soils from Douala for their potential use in road constructions. The hydrological investigations over a period of twenty years showed an average annual temperature of 27.8 °C, and the rainfall of 433 mm. The average relative humidity was 82% throughout the year. Actual evapotranspiration, runoff and infiltration were 48.55%, 39.57% and 11.88% respectively. These parameters are responsible for the fragility of the soil supporting the pavements. The raw materials are presented silico-aluminos-ferruginous-titanous
and consist of quartz (52–72%); kaolinite (20–35%); goethite (4–5%); anatase (3–4%) and feldspar (0–4%). The geological parameters based on silica/alumina ratio indicate that the samples from Bekoko are non-lateritic soils, the Dibamba soil samples are lateritic soils and samples from Lendi are true lateritic soils. These materials are good for sub-base layers. The natural moisture content of the Douala samples ranges from 11% to 24.5%, 19 and 14.9% for the samples of Bekoko, Dibamba and Lendi respectively and less than 35% as recommended by the CEBTP for sub-base materials samples. However, Atterberg's consistency limit tests indicate that the samples have low to moderate plasticity and low swelling potential. According to the HRB classification, the soils sample from Dibamba, Bekoko belong to the A-7-6 group while the Lendi soil samples fall under group A-7-5 which corresponds to clayey soils and are described as fair to poor materials for road construction. The “Guide des Terrassements Routiers” (GTR) classified Dibamba and Bekoko soils samples as fine clayey sand (A2 group) while the samples of Lendi close to weak plastic silt or fine sand without pollution (A1 group). The unified soil classification system (USCS) shows that, majority of samples collected in the study area belongs to SM group (Silty sand) except DB1 and LEN1 samples which are of SC group (clayey sand). The average of the maximum dry density (MDD) values is 1.9 g/cm³ and an average moisture content of 11% corresponds to the lower limit recommended for the use as sub-base materials. The CBR values are lower than 30%, which allows them to be classified in the bearing capacity class S4. Thus, these samples are potentially used as raw material in sub-base layer for T1 traffic (CEBTP). However, their use as base or sub-base construction materials for heavy traffic (T2/T3) requires amended with coarse gravel, cement and or bitumen.

**Declarations**

**Author contribution statement**

Jules Bertrand Penka: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Ursula Joyce Merveilles Pettang Nana: Contributed reagents, materials, analysis tools or data.

Marcelline Blanche Manjia: Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Isaac Yannick Bomeni: Performed the experiments; Analyzed and interpreted the data.

Chrispin Pettang: Conceived and designed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data.

**Additional information**

No additional information is available for this paper.

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