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Interaction of the Mining Environment on the Properties of Hydraulic Mortars in Silty Sands in Togo

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Abstract

The objective of this study is to determine the influence of the surrounding soils on the granular properties of the silty sands of Togo and on the resistance of the mortars. Sand compositions are made by substituting silty sands with clay soil, vegetal soil, lateritic soil or fine elements (<0.08 mm) which are the surrounding land polluting the sands in Togo. After identification tests, the mixtures were used to prepare test specimens of mortar which are subjected to bending and compression. It appears that additions of clay and plastic soils ($ES = 0$, $VBM > 0.53$ and $IP > 19$) from 10% to 35% cause drops in resistance of mortars from 7% to 96%; this loss is 8% to 70% for the rates of addition of less clayey soil ($ES = 33$, $VBM = 0.40$ and $IP = 0$) at rates of 10% to 100%. As for fine powdery soils ($ES = 56.53$ and $VBM = 0.25$), they have virtually no influence on resistance (loss of less than 3% for rates of 100%). Construction stakeholders thus have a decision-making tool for the choice of silty sand extraction zones according to the surrounding land and the quality of the desired concrete.

Keywords

Mortar, Silty Sand, Pollutants, Physical and Mechanical Properties

1. Introduction

In Africa and particularly in Togo, the material most used in the construction of civil engineering works is concrete which is composed of water, binder and aggregates. The most used sands in Togo are sea sands, river sands, resulting from rock crushing and continental dunes. For reasons of coastal erosion, by interministerial decree N° 031/MME/MERF of 5 May 2011, the Togolese state had prohibited the taking of sand from the coast. In the coastal zone as well as in the interior of Togo, the sands are therefore collected in the extraction quarries.

Unlike sea sands which benefit from the dynamic aspect of seawater and therefore very clean devoid of fine elements, silty sands do not benefit from this phenomenon. Soils which often consist of fine, loamy and clay soils which contribute to enriching them with fine, loamy and clay elements resulting from the phenomenon of entrainment by rainwater which infiltrates the soils. The method of extraction also contributes to the pollution of these sands by poor clearance of plant cover and other soils before extraction [1] [2] [3].

Dreux and Gorisse classified the use of sands according to their cleanliness (sand equivalent) [4]. In this logic, a work is carried out in order to characterize the quarries of its silty sands in Togo [1] [5]. Thus the silty sands in operation in Togo are characterized by determining their granular parameters (differential and cumulative distributions, indices, envelope spindle, Hazen and curvature coefficients, granular class and fineness modulus), of their cleanliness and density parameters. Other studies have made it possible to determine a mortar formulation based on this silty sand from Togo for optimal mechanical properties allowing for optimal compressive and flexural resistance [1] [5] [6]. These studies have shown the complexity of the formulation parameters which are functions of the different types of pollutants which constitute the surrounding soils of the silty sands of Togo.

It is therefore a question of researching the effluence of the three fundamental pollutants (clay soil, vegetal soil, lateritic soil) which constitute the surrounding soils with silty sands in Togo, on the properties of this sand and on the mechanical characteristics of the mortars. This will help define the potential of silty sands and make available to designers (engineers, technicians, design office) and especially builders, data on this material, intended for construction uses in Togo.

2. Material and Method

2.1. Material

The materials and materials used for the experiments are given by:

- silty sand and vegetal soil taken from the Aképé-Idavé extraction sites located 20 km northwest of Lomé on the national road N˚ 2; the clay soil of Togblekopé located 15 km north of Lomé on the national road N˚ 1 and the lateritic soil taken from Agoégnive peripheral district of Lomé (see **Figure 1**);
- a mini mortar mixer (**Figure 2(a)**);
- a SILVERCREST brand electronic scale, with a maximum load of 5000 g and a precision of 1 g;
- a LABOTEST brand shaking machine for 90 cycles in 30 seconds with automatic stop (**Figure 2(c)**);
- an oven at a temperature of 105˚C for the conservation of sands and earths;
- an equivalent sand apparatus;
- a series of sieve openings (mm): 0.08, 0.1, 0.125, 0.16, 0.2, 0.25, 0.315, 0.4, 0.5,

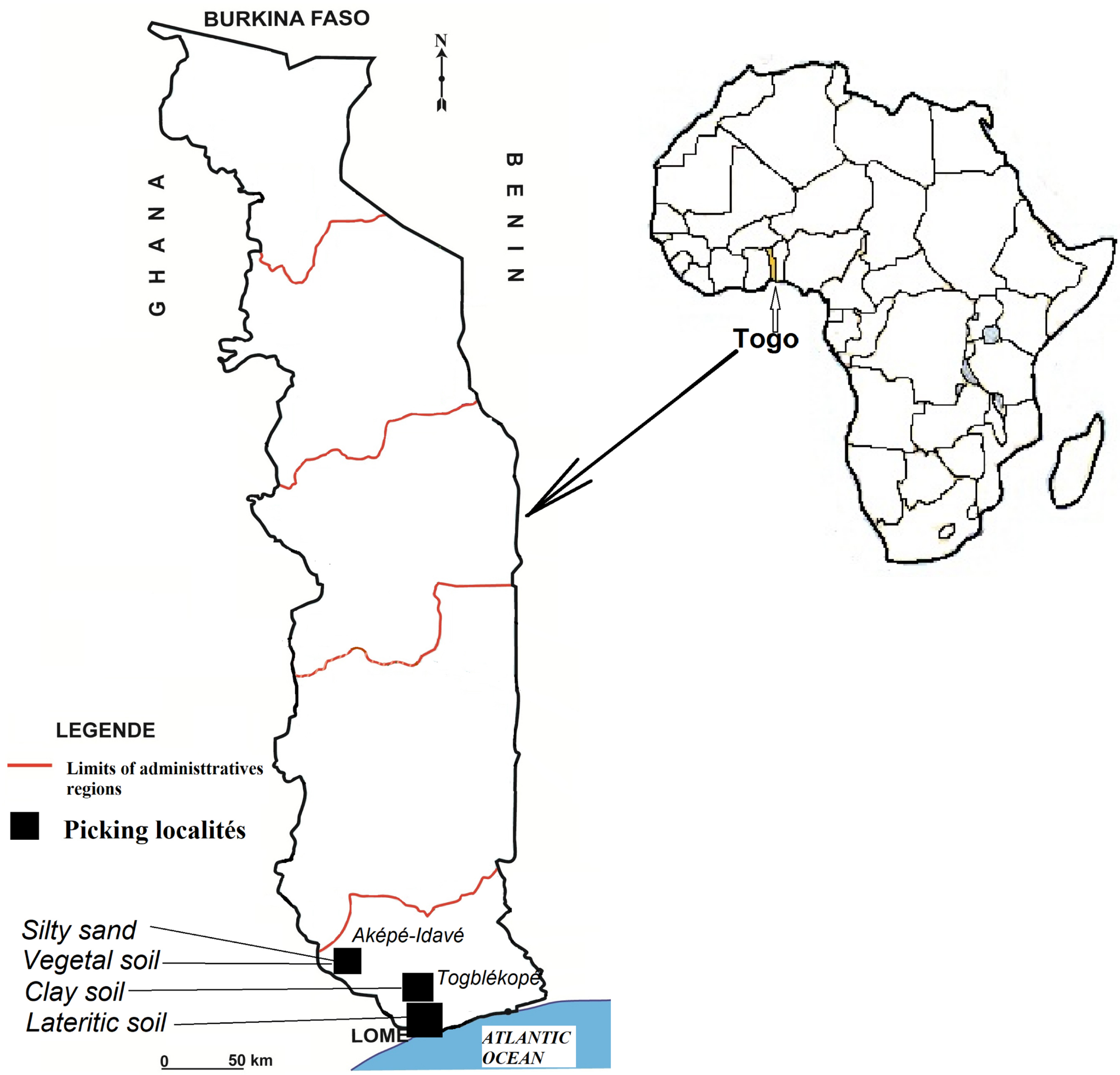

Figure 1. Position of Togo and harvesting areas [13].

0.63, 0, 8, 1, 1.25, 1.6, 2 and 4;
- prismatic molds of dimensions 4 cm × 4 cm × 16 cm (see **Figure 2(b)**);
- a PERIER brand mini press, with a maximum load of 300 kN and a precision of 0.5 kN with the compression and bending cells (see **Figure 2(e)**);
- a water tank for storing the test specimens;
- a transparent tube and a graduated cylinder for absolute density measurement.

2.2. Method

To appreciate the behavior of silty sands with respect to surrounding materials,

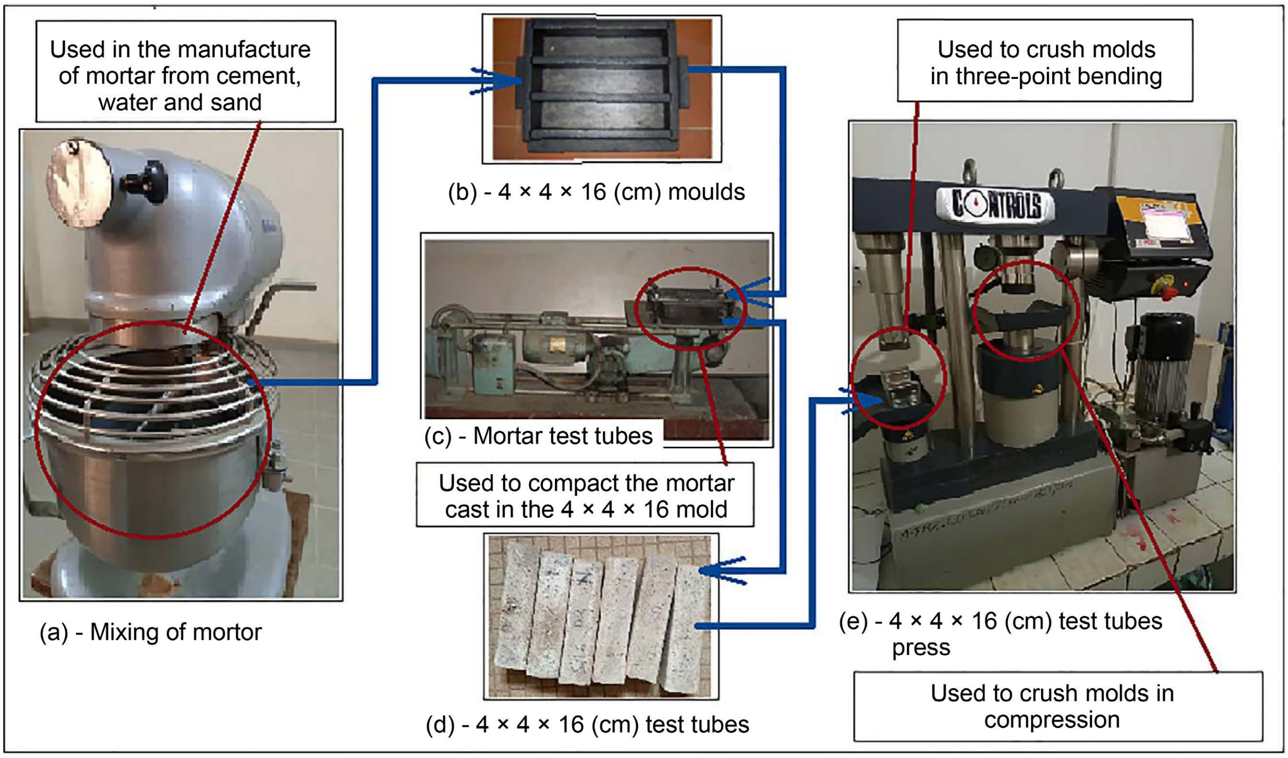

Figure 2. Experimental device for determining mechanical properties [13].

sand compositions are made by substituting Aképé silty sands with Togblekopé clay soil, Aképévegetal soil, Agoenyivélateritic soiland fine elements (<0.08 mm) extracted from silty sand, in proportions of 0 to 100% in steps of 50 g (3.7%). This composition made it possible to obtain 43 mixtures of sands which have undergone identification tests in accordance with standards [7] [8] [9] [10] [11]. The tests performed are density, sand equivalent, Atterberg limits, methylene blue test and particle size.

The 48 mixtures (9 of fine elements of silty sands, 21 of vegetal soil, 9 of lateritic soil and 9 of clay soil) were used to prepare test specimens from the dosage of 1350 g of composite sands, 450 g of cement and 225 g of water [12]. The obtained dosages are kneaded in the mini mortar mixer (Figure 2(a)) and then molded into the 4 cm × 4 cm × 16 cm molds (Figure 2(b)) and then vibrated from the shaking device (Figure 2(c)). The products obtained, demolded after 24 h, are stored in a water tank at a temperature of 20˚. After 28 days of age, 288 (48 × 3 × 2) specimens were compressively crushed after rupturing 144 (44 × 3) by three-point bending from the press (Figure 2(e)). The compressive breaking forces are measured.

3. Results

3.1. Characteristics of the Materials Used

The sand used for the experiment (Table 1) is a sandy loam soil ($VBM \approx 0.25 < 1.5$) very fine ($Mf \approx 1.57 < 2.1$) and not clean ($ES \approx 56.53 < 70$). It is therefore

Table 1. Characteristics of sand and soil materials.

	Apparent density	Absolute density	Fineness modulus	Sand equivalent	Methylene blue value	Liquidity limits	Plasticity limits	Plasticity index
Siltysand	1.57	2.61	1.57	56.53	0.25	-	-	
vegetalsoil	1.52	2.61		33.00	0.40	-	-	-
lateriticsoil	1.29	2.50		-	0.53	32	13	19
Clay soil	1.56	2.57		-	3.40	42	15	27

generally unsuitable for conventional concretes but more suitable for concretes whose ease of implementation is more desirable [4]. These results are consistent with those of the work of Amey K. B. [1] [2] on the silty sands of Togo. As for the properties of the materials used as pollutants during the experiment, they are given as follows (Table 1):

- vegetal soil is a sandy loam soil, not clean and not plastic ($VBM \approx 0.40 < 1.5$, $ES \approx 33.00 < 60$);
- bar earth is a sandy loam soil that is not very plastic with a low swelling potential ($VBM \approx 0.40 < 1.5$, $LL = 32$ and $IP = 19$);
- clayey earth is a clay that is not very plastic with medium swelling potentials ($VBM \approx 3.40 < 1.5$, $LL = 42$ and $IP = 27$).

3.2. Effect of Pollutants on the Properties of Silty Sands

Experiments have shown that:

- The sand equivalent of materials composed with pollutants from non-plastic soils (fine elements from silty sand and vegetal soil) has a linearly decreasing rate (Figure 3). As for materials composed with pollutants from clay soils (lateritic soil and clay soil), they become non-spraying at 10% pollutants and clay soils at rates of 35% ($ES \approx 0$) with exponentially negative appearances. The expressions of these equations are given by (Figure 3):

$$ES_{ss} = -1.729p + 81.426 \quad \text{and} \quad R^2 = 0.9264 \tag{1a}$$

$$ES_{tv} = -0.2197p + 52.261 \quad \text{and} \quad R^2 = 0.9262 \tag{1b}$$

$$ES_{tb} = 42.638\mathrm{e}^{-0.028p} \quad \text{and} \quad R^2 = 0.8115 \tag{1c}$$

$$ES_{ta} = 41.643\mathrm{e}^{-0.028p} \quad \text{and} \quad R^2 = 0.7896 \tag{1d}$$

ES_{ss}, ES_{tv}, ES_{tb}, ES_{ta} represent the equivalence of Sand with pollutants of fine elements of silty sand, vegetal soil, lateritic soil and clay soil, respectively; and p is the pollutant rate (%).

- The addition of plastic pollutants with average swelling potential (clay soil) causes an exponential sensitivity in plasticity for pollutants below 20% ($p <$ 20%). Beyond 20% of swelling plastic pollutants (clay soil) and for pollutants made from non-swelling or weakly swelling materials (vegetal soil, lateritic soil), the sensitivity to plasticity remains moderately increasing (Figure 4).

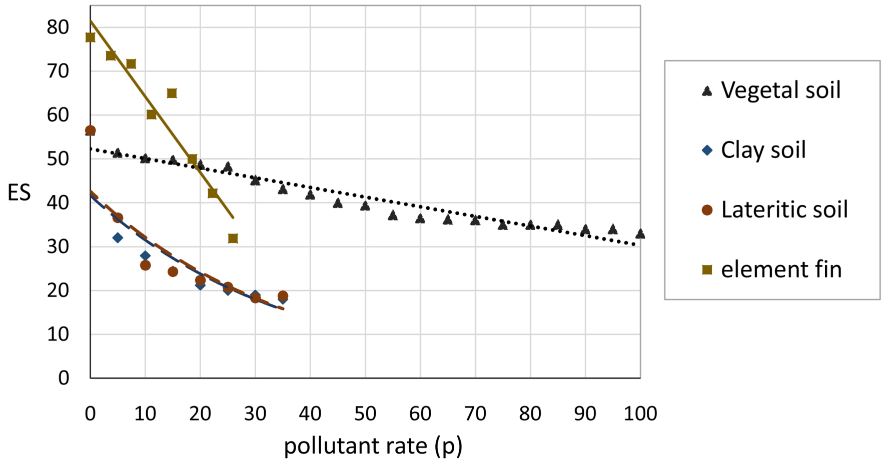

Figure 3. Evolution of the Sand Equivalent (*ES*) as a function of the pollutant rate (*p*).

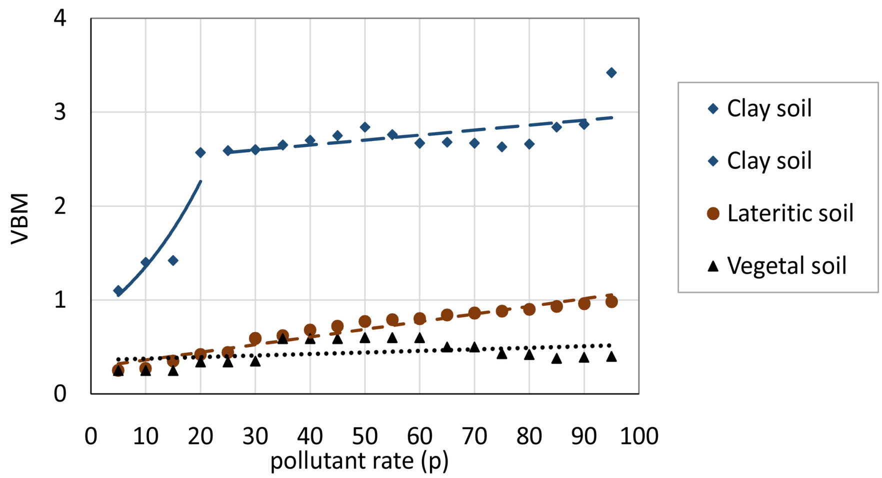

Figure 4. Evolution of the Methylene Blue Value (*VBM*) as a function of the pollutant rate (*p*).

The smoothing equations are given by:

$$VBM_{tv} = -0.0016p + 0.3586 \quad \text{and} \quad R^2 = 0.1292 \tag{2a}$$

$$VBM_{tb} = 0.0082p + 0.2784 \quad \text{and} \quad R^2 = 0.9401 \tag{2b}$$

For $0 \le p < 20$

$$VBM_{ta} = 0.8119e^{0.0512p} \quad \text{and} \quad R^2 = 0.848 \tag{2c}$$

For $20 \le p \le 100$

$$VBM_{ta} = 0.0053p + 2.4365 \quad \text{and} \quad R^2 = 0.3409 \tag{2d}$$

The various parameters of these equations are given by VBM_{tv}, VBM_{tb} and VBM_{ta} which represent the Methylene Blue values of materials composed with pollutants respectively of vegetal soil, lateritic soiland clay soil; *p*, the pollutant rate (%).

- The silty sand used being non-plastic, the addition of non-plastic soils (fine elements from silty sands and vegetal soil) gave a non-plastic material. Compound materials resulting from the addition of plastic pollutants (lateritic soiland clay soil), have become plastic from rates of 35%. This plasticity is linearly increasing for $p > 35\%$ with given equations (Figures 5-7).

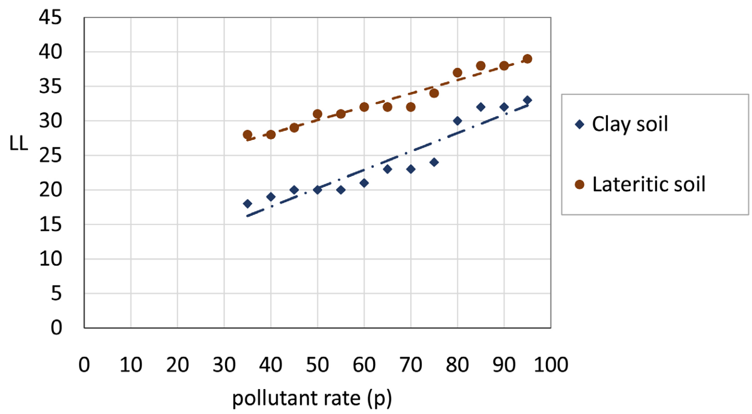

Figure 5. Evolution of the Liquidity Limits (*LL*) as a function of the pollutant rate.

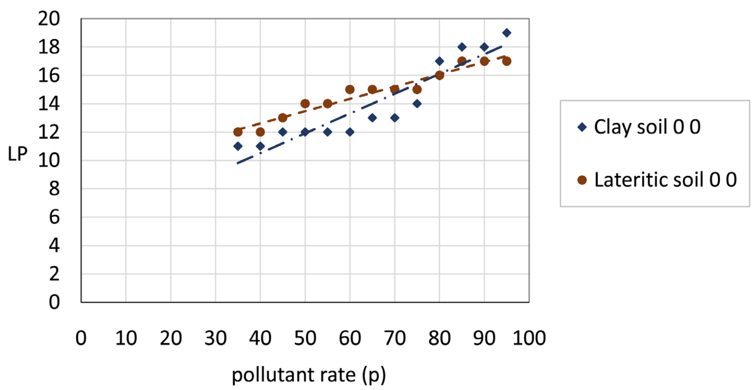

Figure 6. Evolution of the Plasticity Limits (*LP*) as a function of the pollutant rate.

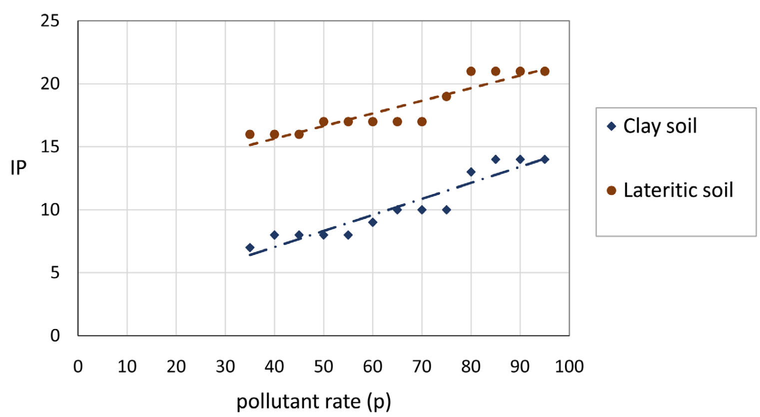

Figure 7. Evolution of Plasticity Indices (*PI*) as a function of the pollutant rate (p).

$$LL_{tb} = 0.1934p + 20.429 \quad \text{and} \quad R^2 = 0.9455 \tag{3a}$$

$$LP_{tb} = 0.0868p + 9.1264 \quad \text{and} \quad R^2 = 0.9445 \tag{3b}$$

$$IP_{tb} = 0.10p + 11.654 \quad \text{and} \quad R^2 = 0.8474 \tag{3c}$$

$$LL_{ta} = 0.267p + 6.8736 \quad \text{and} \quad R^2 = 0.8906 \tag{3d}$$

$$LP_{ta} = 0.1396p + 4.9286 \quad \text{and} \quad R^2 = 0.8688 \tag{3e}$$

$$IP_{ta} = 0.1275p + 1.9451 \quad \text{and} \quad R^2 = 0.8983 \tag{3f}$$

With p, the pollutant rate (%); LL_{tb} and LL_{ta}, the liquidity limits, LP_{tb} and LP_{ta}, the plasticity limits and IP_{tb} and IP_{ta}, the plasticity indices of sand composed respectively with the elements lateritic soiland clay soil.

3.3. Effect of Pollutants on the Compressive Resistance of Mortars

The compressive strengths of specimens of mortars based on materials composed with fine elements derived from silty sands, is almost constant regardless of the level of pollutants (Figure 8); those whose pollutants are clay soils with $VBM < 1.5$ (lateritic soiland vegetal soil), have linearly decreasing patterns; as for the materials composed with plastic clay soils ($VBM > 2.5$), they give resistance with an exponentially negative appearance (Figure 8). Plastic pollutants ($VBM \neq 0$ and $IP \neq 0$) make the mortars less resistant and this depending on the clay content. The expressions of the compressive resistance of mortars (σ_{ss}, σ_{tv}, σ_{tb}, σ_{ta}) with pollutants respectively of fine elements of silty sand, vegetal soil, lateritic soiland clay soil as a function of the pollutant rate (p in %) are given by Equations 4(a) to 4(d):

$$\sigma_{ss} = 0.0077p + 32.951 \quad \text{and} \quad R^2 = 0.007 \tag{4a}$$

$$\sigma_{tv} = -0.1623p + 23.4160 \quad \text{and} \quad R^2 = 0.9054 \tag{4b}$$

$$\sigma_{tb} = -0.131p + 16.174 \quad \text{and} \quad R^2 = 0.6944 \tag{4c}$$

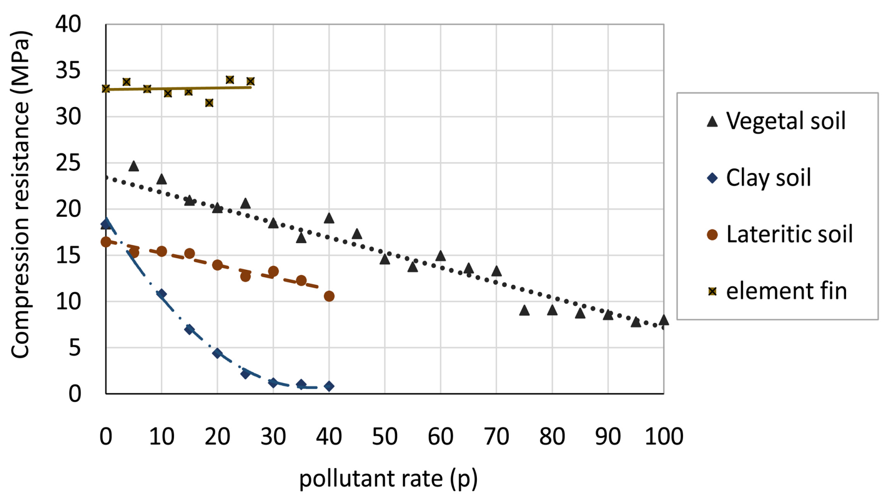

Figure 8. Evolution of compressive resistance as a function of the pollutant rate (p).

$$\sigma_{ta} = 0.0135p^2 - 0.9973p + 19.058 \quad \text{and} \quad R^2 = 0.9954 \quad (4d)$$

3.4. Correlation between Resistance of Mortar and Sand Properties

The resistanceof mortars made from composite materials increase with Sand Equivalent (*ES*) for all pollutants. But they are lower for pollutants made from plastic soils than for non-plastic soils (Figure 9 and Equations 5(a) to 5(b)). The more pulverulent the materials (high *ES*, low *IP* and low *VBM*) the higher the resistances. Equations 5(a)-(d) give the expressions of the compressive resistance (σ_{ss}, σ_{tv}, σ_{tb} and σ_{ta}) of the mortars composed respectively of fine elements, vegetal soil, lateritic soiland clay soil as a function of the Sand Equivalent (*ES*):

$$\sigma_{ss} = -0.0003.10^{-6}(ES)^{5.6275} \quad \text{and} \quad R^2 = 0.9291 \quad (5a)$$

$$\sigma_{tv} = 0.6600(ES) - 11.943 \quad \text{and} \quad R^2 = 0.7798 \quad (5b)$$

$$\sigma_{tb} = 0.0907(ES) + 11.798 \quad \text{and} \quad R^2 = 0.6199 \quad (5c)$$

$$\sigma_{ta} = 16.778\ln(ES) \quad \text{and} \quad R^2 = 0.9075 \quad (5d)$$

The compressive resistance (σ_{tv}, σ_{tb} and σ_{ta}) of mortars decreases with increasing methylene blue value (*VBM*) for two materials composed with plastic soils with Equations 6(a)-(c) (Figure 10):

$$\sigma_{tv} = 12.892(VBM) + 20.836 \quad \text{and} \quad R^2 = 0.093 \quad (6a)$$

$$\sigma_{tb} = -10.434(VBM) + 18.402 \quad \text{and} \quad R^2 = 0.8626 \quad (6b)$$

$$\sigma_{ta} = -7.0876(VBM) + 20.389 \quad \text{and} \quad R^2 = 0.9300 \quad (6c)$$

3.5. Effects of Pollutants on the Resistance of Mortars

While powdery materials (fine silty sand elements of *ES* ~ 56.53, *VBM* ~ 0.25 and *IP* = 0) give negligible loss of resistance (loss of resistance less than 3% at 100% pollutant rate), they are more pronounced for materials which lose their plasticity. Thus (Figure 11 and Figure 12).

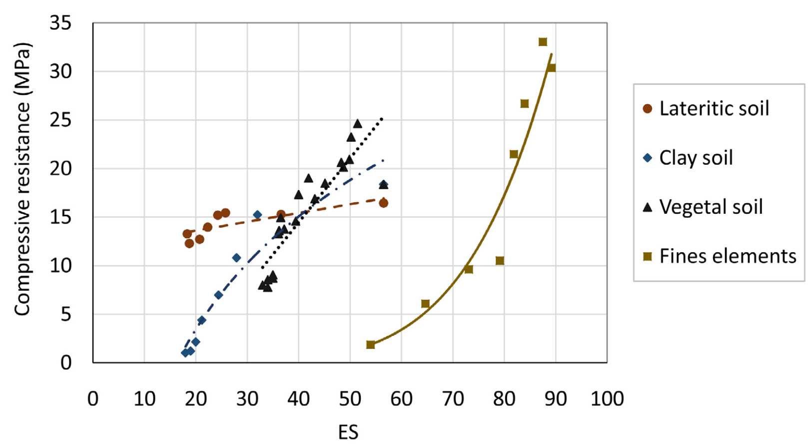

Figure 9. Correlation between compressive strength and sand equivalent (*ES*).

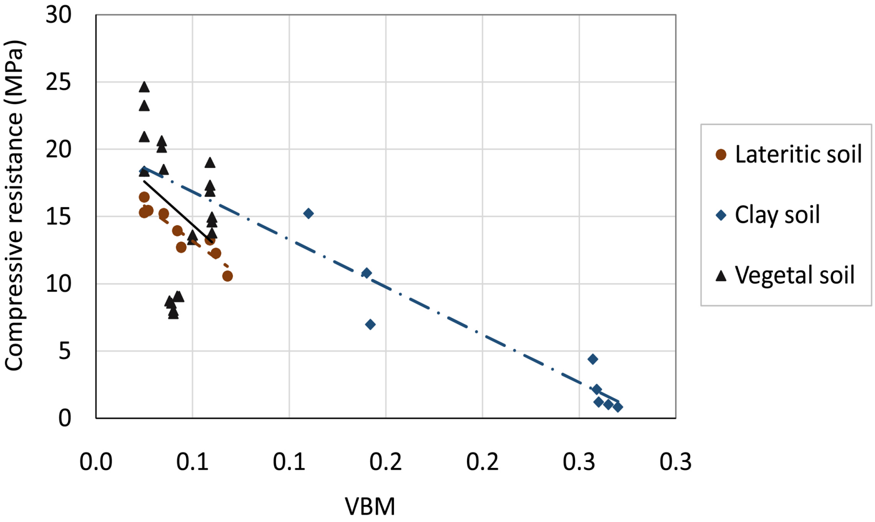

Figure 10. Correlation between compressive resistance and Methylene Blue Value (*VBM*).

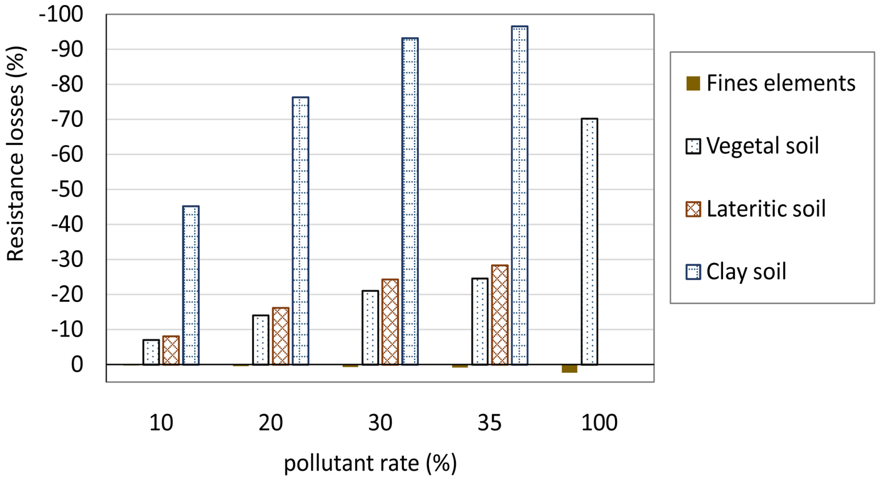

Figure 11. Resistance losses for each type of pollutant.

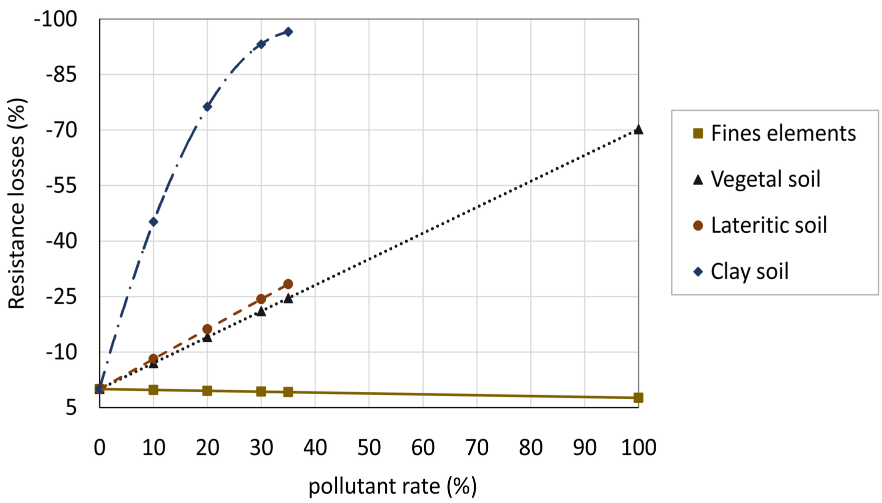

Figure 12. Evolution of resistance losses as a function of the pollutant rate.

- For rates of vegetal soil ($ES \sim 33$, $VBM \sim 0.4$ and $IP = 0$) of 10% the loss is about 7%, this loss increases to about 24.5% and 70% respectively to 35% and 100% with as Equation 8(a);
- As for the lateritic rate ($ES = 0$, $VBM \sim 0.53$ and $IP \sim 19$) of 10% and 35%, the losses are respectively about 8% and 28.4%. Beyond 35%, the loss is 100%; Equation 8(b) illustrates this loss of strength;
- The losses are respectively about 45% and 96.5% for clay soil rates ($ES = 0$, $VBM \sim 3.40$ and $IP \sim 27$) of 10% and 35%, Beyond 35%, the loss is 100%; The equations for these losses are from 7(a) to 7(c).

$$\Delta_{ss}(p) = 0.0234p \quad \text{and} \quad R^2 = 1 \tag{7a}$$

$$\Delta_{tv}(p) = -0.7019p + 0.0003 \quad \text{and} \quad R^2 = 1 \tag{7b}$$

$$\Delta_{tb}(p) = -0.8099p \quad \text{and} \quad R^2 = 1 \quad \text{for} \quad p \le 35\% \tag{7c}$$

$$\Delta_{ta}(p) = 0.0705p^2 - 5.2241 - 0.018 \quad \text{and} \quad R^2 = 1 \quad \text{for} \quad p \le 35\% \tag{7d}$$

With p, the pollutant rate (%); Δ_{ss}, Δ_{tv}, Δ_{tb} and Δ_{ta}, the losses of resistance of mortars composed respectively of fine elements, vegetal soil, lateritic soil and clay soil.

4. Discussion

For powdery materials ($VBM \sim 0$ and $IP = 0$), the compressive resistance of mortars are higher regardless of the value of the Sand Equivalent (ES). In the case of plastic pollutants ($VBM \neq 0$ and $IP \pm 0$), the resistances are very sensitive to the variation of the Sand Equivalent (ES) [4]. Plastic elements are therefore a handicap for improving the resistance of concrete. Thus the Sand Equivalent (ES) of powdery soils has less influence on the quality of concrete for powdery soils. This would be due to the screens formed by the clays on the aggregate grains preventing them from adhering to the binders; which is not the case for powdery (non-plastic) soils. Also, clay soils being finer ($\theta < 0.002$ mm), the quantity of water of hydration of the binder (cement) becomes insufficient compared to that of silts (0.02 mm < $\theta < 0.002$ mm) and fine sands (0.08 mm < $\theta < 0.02$ mm) thus causing the loss of resistance [1] [2] [13] [14] [15]. Knowing the Sand Equivalent of a material is therefore not a sufficient condition for concluding the quality of concrete that can be expected. It is important to research in addition to this parameter, the nature of the materials: powdery, silty, plastics, swelling. So in addition to Sand Equivalent, it is important to make sure that the materials are powdery, non-clayey, non-plastic and non-swelling ($VBM \sim 0$, $LL = 0$, $LP = 0$ and $IP = 0$).

5. Conclusion

Since silty sands are continental sands, they are subject to pollution from other surrounding materials. This study made it possible to highlight the influence of the soils surrounding the silty sands of Togo on the granular properties of the latter and on the resistance of the mortars. The study has shown that powdery soils (*IP* = 0) hardly influence the mechanical properties of mortars (strength losses of less than 1%). Low plastic soils with zero or low swelling potential cause strength losses that can reach 25%. As for powdery and swelling soils, they are very harmful as materials for mortar and concrete, because they cause resistance losses which reach 97%. Those involved in constructions using silty sands in Togo must therefore ensure that the materials are powdery, non-clayey, non-plastic and non-swelling ($VBM \sim 0$, $LL = 0$, $LP = 0$ and $IP = 0$) before they are not considered as materials for mortars and concrete. This study will lead to the determination of the constants of the mortar formula, constants which are functions of the different properties of the sands [1] [14].

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Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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