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Reduction in Water Erosion of Uncoated Roads in Lomé in Togo: Correlation Slope, Width and Water Sheet of Roads

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Abstract The unpaved roads of Lomé in Togo are increasingly eroded by runoff waters. These waters dig sometimes great gullyings on the roads. The runoff waters make the roads impracticable, and they are very often dangerous for populations. The current project consists in determining the compensation slope of the roads in Lomé in order to reduce the water erosion. 330 sediment samples are taken from 110 roads in Lomé, and then subjected to granulometric analyses and identification tests. From the slope compensation theory, the slope that makes it possible to avoid the road erosion is determined for any right-of-way of roads and water sheet. As a result compensation slopes (p) exponentially decrease with roads' right-of-way (L) lying between 3 m and 20 m ($p=aL^b=ae^{b\ ln\ (L)}$) and become stationary beyond 20 m. They are also decreasing from the sheet 100 mm to 350 mm for any right-of-way of the road. The required slopes for unpaved roads are between 0.23% and 2.92% with an average of 0.92 % in order to keep them from water erosion. Equations and graphs are established to help deducting slopes no matter how long the road is (L) and how high the sheet is (h).

Keywords: *uncoated roads, Togo, water erosion, compensation slope*

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1. Introduction

Erosion is a natural and very complex phenomenon that keeps changing the structure of soils. Four (4) main factors influence erosion: rainfall, relief, soil, human activity. Water erosion might be the major cause of mass draining of the soil.

Construction of coated roads is a very costly work, and this cannot be accomplished until a feasibility study is carried out in order to evaluate the cost-effectiveness of such investment. Thus, in the sub-Saharan African countries, only the big roads within towns and national roads are hydrocarbon-coated or coated with paving stones. The proportion of the paved roads is then much lower than that of unpaved roads on the urban network as well as on the whole road network in these countries. In Togo for instance, one of the sub-Saharan African countries, the proportion of unpaved roads and streets accounts for 82.13% [1].

a- Erosion has taken off the soil on a depth of 50 cm at the exterior face of the building.

b- Erosion has transformed the road into a duct of more than 5 m deep leading to the collapse of houses.

Figure 1. Example of the impact of water erosion on two roads in the Agoè area in Lomé (Togo)

In the urban network where roads are characterized by a significant built-up surface and then waterproof, the infiltration of rainwater is therefore largely reduced. This reduction in rainwater infiltration increases their runoff on the roads that are for the most part uncoated. Thus, many uncoated roads are turned into ducts by runoff water. They present then signs of advanced degradation due to erosion and become, therefore, impracticable and very often dangerous for populations (Figure 1a and Figure 1b).

Because the extent of the phenomenon, many studies have been completed on the water erosion of soils. These studies mainly focused on the effects of erosion on the farming lands or in rural areas, particularly, the transport effect of soils causing the loss of fertility on farming lands [2,3]. Relations are defined between losses of soils, due to water erosion, soil slopes [4], the lengths of slopes [5], rushed water sheets [6], the state of surface and soil cover [7] and the liquid debit [8], etc. The main purpose this study is the contribution toward reducing water erosion of unpaved roads through the search for correlation between compensation slopes, lengths of roads and water sheets of ducts that characterize urban unpaved roads of Lomé in Togo, a sub-Saharan African country. Graphs and formula will make it possible for of civil engineering professionals to have data available for the construction of unpaved roads.

2. Theoretical considerations

2.1. Average Perimeter

The purpose of this study is to analyze the effect of water erosion on the roads. The latter will be considered as rectangular ducts subjected to the runoff of rainwaters. Thus, the expression of the average perimeter is as follows:

$$R_m = \frac{S}{C} \tag{1}$$

With S, watered surface and C, watered perimeter given by:

$$S = L.h \tag{2a}$$

$$C = 2h + L. \tag{2b}$$

In these equations L and h are respectively the watered length and the height of the duct (Figure 2).

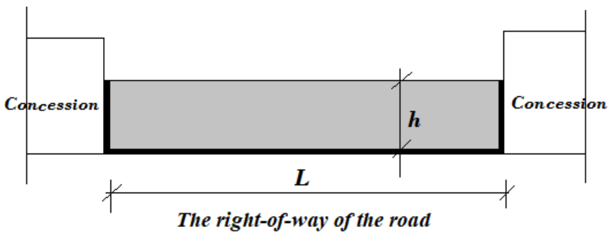

Figure 2. Watered surface and perimeter of the duct

Thus:

$$R_m = \frac{Lh}{2h+L} \tag{3}$$

This allows to deduct the coefficient of the form (m) given by:

$$m = \frac{R_m}{h} = \frac{L}{L+2h}. \tag{4}$$

2.2. Equation of the Movement

A moving drop of water in a duct undergoes a driving force the expression of which is given by the equation (5) [9]:

$$Fe = \rho_e LS \sin\alpha \tag{5}$$

Where ρ_e is the volume mass of the liquid and a the angle of the bottom of bed in relation to the horizontal plan.

As for the delaying force (resistant) caused by the cohesion between the water drop and the bed, it is expressed in the following:

$$Fr = \rho_e LC\left(c_1 v + c_2 v^2\right). \tag{6}$$

In this expression v indicates the speed of the movement of the drop, c_1 and c_2 are perimeters defined by Prony ($c_1 = 0{,}000044$ et $c_2 = 0{,}000309$) and by Eytedwein ($c_1 = 0{,}000024$ et $c_2 = 0{,}000366$) [9].

The equation of the uniform movement is given by the balance between the impulsion force (movement) and the delaying force (resistance) ($F_e = F_r$).

From equations (5) and (6) we deduct the movement equation given by:

$$R \sin\alpha = av + bv^2 \tag{7}$$

According to Darcy and Bazin who made a lot of experiments, the uniform movement equation may be given by:

$$\frac{R_m \sin\alpha}{v^2} = n\left(1 + \frac{K}{R_m}\right). \tag{8}$$

For watercourses carrying rollers**,** this expression (8) becomes:

$$\frac{R_m \sin\alpha}{v^2} = 0.00040\left(1 + \frac{1.75}{R_m}\right). \tag{9}$$

Thus, the speed v given by:

$$v = \sqrt{\frac{R_m \sin\alpha}{0.00040\left(1 + \frac{1.75}{R_m}\right)}}. \tag{10}$$

2.3. Impulse Strength and Friction Strength

Consider a particle with dimensions x, y and z, put on the bottom of bed in slope, if the direction of movement of the particle is x, the impulse produced by the shock of the fluid stream on the particle will be given by the expression:

$$F_i = (K + K')\rho_e yz \frac{v^2}{2g}. \tag{11}$$

According to the works of Dubuat [9] the coefficients of cubic particles are given by: *K=1,19* et *K'=0,27*.

The friction strength F_f of the particle on the bed is given by:

$$F_f = (\rho_c - \rho_e)\, xyzf \cos\alpha \tag{12}$$

With f coefficient of friction; its value for the case of friction between stone is f = 0.76, P_c the volume mass of the dislodged particle.

There will be movement of the particle if $F_i > F_f$. The limit speed of movement of the particle will then be given by the expression:

$$v \geq \sqrt{\frac{0,76(\rho_c - \rho_e)\, x \cos\alpha}{0,0744\rho_e}}. \tag{13}$$

2.4. Compensation Slope

The compensation slope will be given by the balance of the two speeds given by the equations (10) and (13). Thus:

$$tg\alpha = \frac{\sin\alpha}{\cos\alpha} = \frac{3.04x(\rho_c - \rho_e)\left(1 + \frac{1.75}{R_m}\right)}{744\rho_e R_m}. \tag{14}$$

We deduct from this the compensation slope (in %) given by:

$$p = 100tg\alpha = \frac{304x(\rho_c - \rho_e)\left(1 + \frac{1.75}{R_m}\right)}{744\rho_e R_m}. \tag{15}$$

This expression (15) of the compensation slope is a function of the size of dislodged grains x, the volume mass ρ_c, and the average perimeter R_m of the duct.

3. Equipment, Materials and Method

For an identification of sand sediments resulting from the erosion of unpaved roads of lagoon area of Lomé (Figure 3), the most vulnerable area to water erosion, collections of 330 samples of sediments are performed on 110 roads. Laboratory tests are carried out on these samples according to norms NF EN 933-1 [10], NF EN 933-2 [11], NF ISO 9276-1 [12], NF EN 933-8 [13], NF EN 12620 [14]:

- Granulometric analysis (on a game of sieve of the series 0.063-0.08-0.125-0.25-0.5-1-2-4 and 5 mm) for the determination of differential (qr) and cumulative (Qr) distributions, granular class (d/D) and the module of fineness (Mf);
- Physical tests (absolute densities (d_{ab}), apparent density (d_{ap}) and the equivalent of sand (ES)).

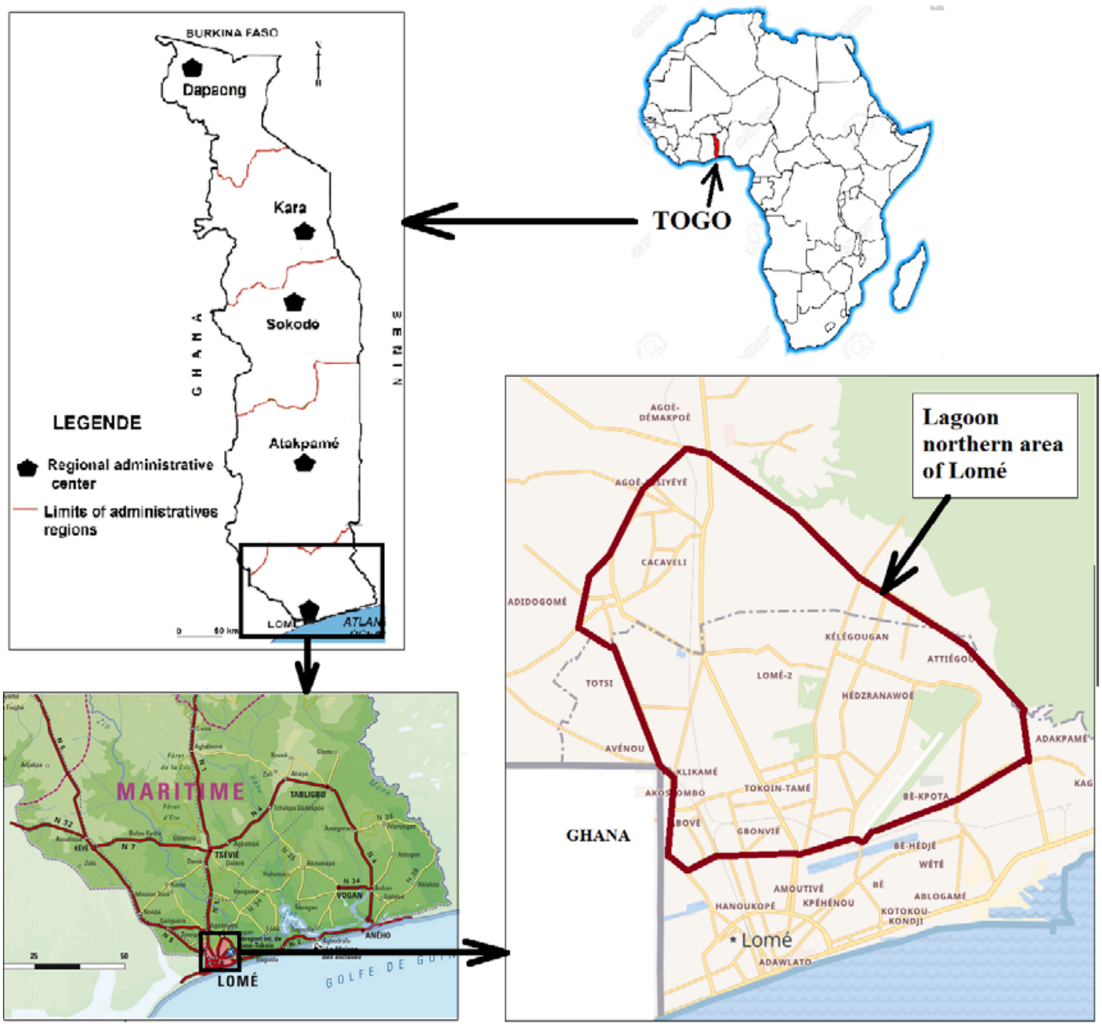

Figure 3. Lagoon northern area of Lomé in Togo

According information data collected from the cadaster department of Togo, the roads in Lomé, under consideration in the process of study, have right-of-ways varying from 3 m to 70 m. Roads of 22 width (right-of-ways): 3, 4, 6, 7, 8, 9, 10, 12, 14, 16, 18, 20, 25, 30, 35, 40, 45, 50, 55, 60, 65 and 70 (in m) are selected. The consideration of the level of waters on some roads indicates the heights of runoff water on these roads not exceeding 350 mm. Six (6) values of water sheets are then the subject of the present study: 100, 150, 200, 250, 300 and 350 (in mm). The compensation slopes of these roads are searched for through modelisation of the draining of runoff waters that trigger the movement of particles by way of water erosion.

4. Results

Table 1 and Figure 4 provide the results (average of 330 samples) of determining characteristics of sediments due to water erosion of roads in the lagoon northern area in Lomé.

The findings from Table 1 and Figure 4 show that the road sediments of the lagoon northern area are clean and too fine sands (*ES~87.94* >70 and M*f~1.92<2.1*) of granular class 0/1 and absolute density of *2.61* and apparent density of 1.49. These properties of road sands are almost similar to these of fine sands of Togolese littoral at PK7 and siliceous sands of Togo that are too fine (M*f<2.1*), of absolute densities between 2.65 and 2.75 and apparent densities between 1.5 and 1.55 [15-20]. The similarity between these three materials is due their closeness and therefore to their composition which is the silica (proportion at least equal to 66.32).

From the absolute density of sediments ($\rho_c = \rho_{ab} = 2,61$), the dimension of the big particle (x=D=1), the dimensions of the duct (L=3 m to 70 m), the water sheets (h = 100 mm to 350 mm) and by the application of the formula (15), the compensation slopes of Lomé's roads are determined (Table 2, Figure 5 and Figure 6).

Table 1. Characteristics of sediments of unpaved roads of lagoon northern area in Lomé, sands of the littoral of Lomé at KP7 and siliceous sands of Togo

Type of Sand	Number of samples	Class granular d/D (mm)	Mass absolute volume ρ_{ab} (kg/m^3)	Mass apparent volume ρ_{ap} (kg/m^3)	Module of fineness Mf	Equivalent of sand ES (%)
Sand of Roads of The lagoon Northern area Of Lomé	330	0/1	2.61	1.49	1.92	87.94
Sand of littoral of Lomé at PK7 [15,16,19]	210	0/1.25	2.66	1.55	1.514	100
Silty Sand of Togo [18,20]	72	0/1	2.72	1.50	1.966	66.32

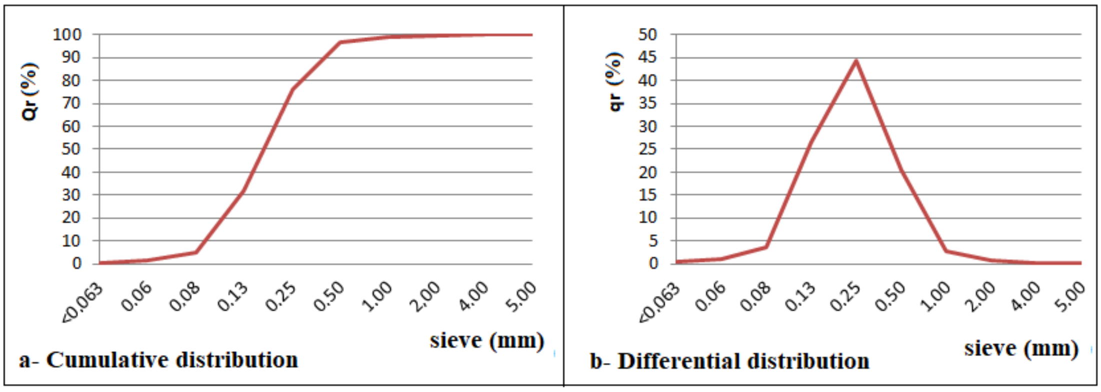

Figure 4. Granulometric distributions of sediments of roads of lagoon northern area in Lomé

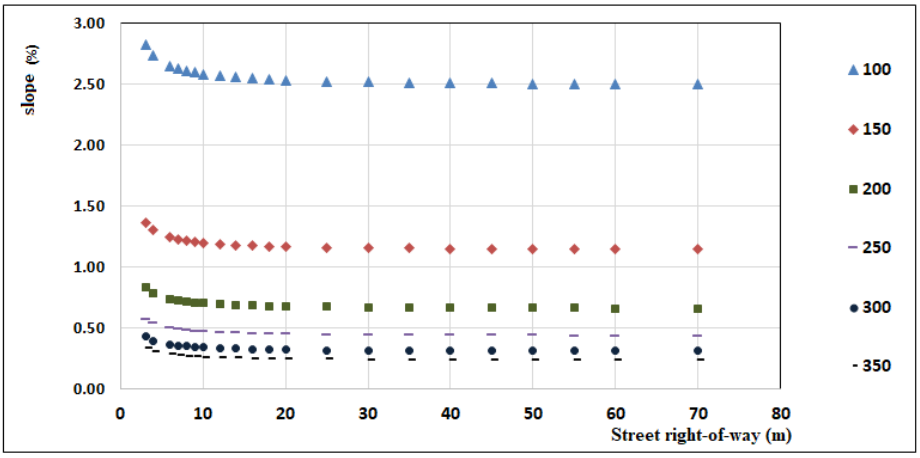

Figure 5. Evolution of the compensation slope depending on the width of roads

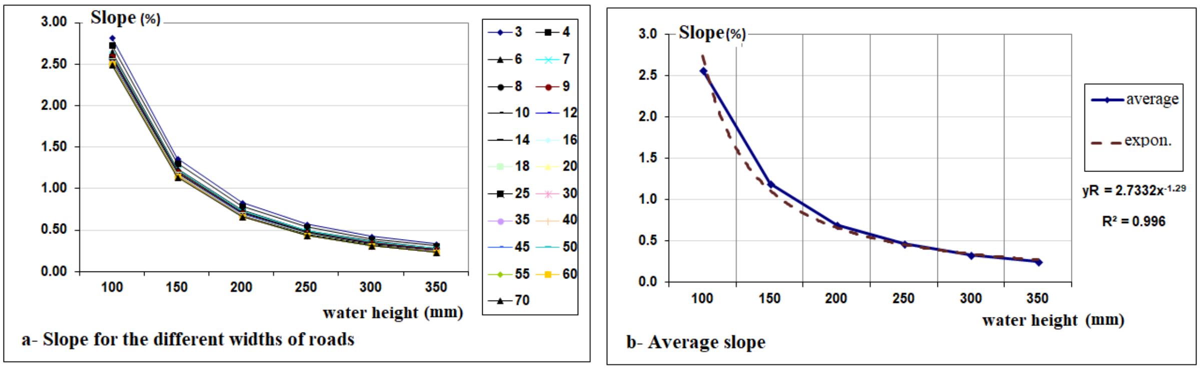

Figure 6. Evolution of the compensation slope depending on the water sheets (heights)

Table 2. Compensation slope (%) of unpaved roads of the lagoon northern area of Lomé

Ref	Road width (m)	Water height (mm)						Average slope	Minimum slope	Maximum slope
		100	150	200	250	300	350			
1	3	2.82	1.36	0.83	0.57	0.43	0.34	1.06	0.34	2.82
2	4	2.73	1.30	0.79	0.54	0.40	0.31	1.01	0.31	2.73
3	6	2.65	1.25	0.74	0.50	0.37	0.28	0.96	0.28	2.65
4	7	2.63	1.23	0.73	0.49	0.36	0.27	0.95	0.27	2.63
5	8	2.61	1.22	0.72	0.48	0.35	0.27	0.94	0.27	2.61
6	9	2.60	1.21	0.71	0.48	0.35	0.26	0.93	0.26	2.60
7	10	2.58	1.20	0.71	0.47	0.34	0.26	0.93	0.26	2.58
8	12	2.57	1.19	0.70	0.46	0.34	0.26	0.92	0.26	2.57
9	14	2.56	1.18	0.69	0.46	0.33	0.25	0.91	0.25	2.56
10	16	2.55	1.18	0.69	0.46	0.33	0.25	0.91	0.25	2.55
11	18	2.54	1.17	0.68	0.45	0.33	0.25	090	0.25	2.54
12	20	2.54	1.17	0.68	0.45	0.32	0.25	0.90	0.25	2.54
13	25	2.53	1.16	0.68	0.45	0.32	0.24	0.90	0.24	2.53
14	30	252	1.16	0.67	0.44	0.32	0.24	0.89	0.24	2.52
15	35	2.51	1.15	0.67	0.44	0.32	0.24	0.89	0.24	2.51
16	40	2.51	1.15	0.67	0.44	0.31	0.24	0.89	0.24	2.51
17	45	2.51	1.15	0.67	0.44	0.31	0.24	0.89	0.24	2.51
18	50	2.51	1.15	0.67	0.44	0.31	0.24	0.88	0.24	2.51
19	55	2.50	1.15	0.66	0.44	0.31	0.24	0.88	0.24	2.50
20	60	2.50	1.15	0.66	0.44	0.31	0.24	0.88	0.24	2.50
21	70	2.50	1.14	0.66	0.44	0.31	0.23	0.88	0.23	2.50
Average slope		2.57	1.19	0.70	0.47	0.34	0.26	0.92		
Minimum slope		2.50	1.14	0.66	0.44	0.31	0.23		0.23	
Maximum slope		2082	1.36	0.83	0.57	0.43	0.34			2.82

The equations of the smoothing of the slope (p in %) depending the right-of-way of roads (L in m) are given for the different heights of water (h in mm) by (Figure 5):

For h=100 mm

$$p_{100} = 2.9344 L^{-0.052} R^2 = 0.9270 \; for \; L \le 20m$$

$$p_{100} = 2.6146 L^{-0.011} R^2 = 0.9680 \; for \; L \ge 20m. \quad (16a)$$

For h=150 mm

$$p_{150} = 1.4458 L^{-0.076} R^2 = 0.9290 \; for \; L \le 20m$$

$$p_{150} = 1.2224 L^{-0.016} R^2 = 0.9680 \; for \; L \ge 20m. \quad (16b)$$

For h=200 mm

$$p_{200} = 0{,}8977 L^{-0{,}099} R^2 = 0{,}9311 \; for \; L \le 20m.$$

$$p_{200} = 0{,}7223 L^{-0{,}021} R^2 = 0{,}9680 \; for \; L \ge 20m \quad (16c)$$

For h=250 mm

$$p_{250} = 0{,}6316 L^{-0{,}121} R^2 = 0{,}9320 \; for \; L \le 20m.$$

$$p_{250} = 0{,}4850 L^{-0{,}026} R^2 = 0{,}9689 \; for \; L \ge 20m. \quad (16d)$$

For h=300 mm

$$p_{250} = 0{,}4850 L^{-0{,}026} R^2 = 0{,}9689 \; for \; L \ge 20m.$$

$$p_{300} = 0{,}3529 L^{-0{,}031} R^2 = 0{,}9690 \; for \; L \ge 20m. \quad (16e)$$

For h=350 mm

$$p_{350} = 0{,}3852 L^{-0{,}161} R^2 = 0{,}9350 \; for \; L \le 20m$$

$$p_{350} = 0{,}2714 L^{-0{,}035} R^2 = 0{,}9690 \; for \; L \ge 20m. \quad (16f)$$

Table 2, Figure 5 and and the equations (16a) to (16f) indicate that the compensation slopes exponentially go down with the right-of-ways of roads between 3 m to 6 m, become stationary in the interval between 6 m and 20 m and are almost constant beyond 20 m. The slopes present decreasing trends of the sheet 100 mm to 350 mm for any right-of-ways of road (Figure 6).

The slopes between 0.23% and 2.92% with an average of 0.92%, may be brought into two categories: slopes of right-of-ways under 20 m and those of right-of-ways beyond 20 m. Table 3 provides the values of the two categories of compensation slopes.

Table 3. Compensation slopes (p in %) of Lomé's roads

Ref.	1	2	3	4	5	6
Water height h (mm)	100	150	200	250	300	350
Slope p (%) for L<20m	2.82	1.36	0.83	0.57	0.43	0.34
Slope p (%) for L>20m	2.51	1.50	0.67	0.44	0.31	0.24

5. Discussion

In order to ensure an acceptable drainage of runoff waters on the roads, it is recommended to get a gradient and others between 0.5% and 1% with an average value of around 0.7% [21]. The margin of the slopes in the case of the present study that is 0.23% to 2.92%, with an average value of 0.92%, includes the recommended margin (0.5% to 1%).

The expressions of the slopes (p in %) depending on the width of road (L in m) (equations (16a) to (16f)) are of the form:

$$p_h = aL^b = ae^{b\ln(L)} \text{ and } R^2 = 0{,}90 \qquad (17)$$

With:

p_h, the compensation slope (in %) for a height of water h (in mm)

L, the width of road (in m)

R^2, the determination coefficient

a and b constant functions of geometric characteristics of the duct (width L) and dislodged particles.

The extraction of coefficients a, b and R^2 of these equations (16a) to (16f) has helped determining the correlations between these parameters and the height of water (sheet) h (Figure 7). The curves of smoothing of these parameters depending on the height of water h (in mm) provide the equations (18a) to (18b):

For L≤20m:

$$\begin{cases} a = 5004.7h^{-1.623} \text{ with } R^2 = 0.99 \\ b = -0.0004h - 0.0104 \text{ with } R^2 = 0.99 \\ R^2 = 0.00003h - 0.9241 \text{ with } R^2 = 0.98 \end{cases} \qquad (18a)$$

For L≥20m:

$$\begin{cases} a = 10696h^{-1.809} \text{ with} R^2 = 0.99 \\ b = -0.0001h - 0.0015 \text{ with } R^2 = 0.99 \\ R^2 = 0.000005h + 0.9673 \text{ with} R^2 = 0.80 \end{cases} \qquad (18b)$$

The correlations between the slopes (p in %), the sheets (h in mm) and the widths of road (L in m) are then given by:

- For L≤20 m

$$\begin{aligned} p(h,L) &= 5004.7h^{(-1.623)}L^{-(0.0004h+0.0104)} \\ &= 5004.7e^{-1.623\ln(h)}e^{-0.0004h\ln(L)}e^{-0.0104ln(L)} \qquad (19a) \\ &= 5004.7e^{A}. \end{aligned}$$

With:

$$A_1 = -\left(1.623\ln(h) + 0.0004h\ln(L) + 0.0104\ln(L)\right)$$

- Pour L≥20 m

$$\begin{aligned} p(h,L) &= 10696h^{(-1.809)}L^{-(0.0001h+0.0015)} \\ &= 10696e^{-1.809\ln\ln(h)}e^{-0.0001h\ln\ln(L)}e^{-0.0015\ln(L)} \qquad (19b) \\ &= 10696e^{A} \end{aligned}$$

With:

$$A_2 = -\left(1.696\ln(h) + 0.0001h\ln(L) + 0.0015\ln(L)\right).$$

Table 4 and Table 5 show the relative errors of results gained from the equations (19a) and (19b) with respect to Table 2. It emerges from this that the errors on the calculated slopes are lying between 0.03% and 7.13%. The slopes provided by the equations (19a) and (19b) may then represent the theoretical values of Table 4 and Table 5 at 92.87%.

Table 4. Relative errors on calculated slopes for h=100 , h=150mm, h=200 mm

Ref	Street right-of-way L (m)	Water height h (mm)								
		100			150			200		
1	3	2.82	2.69	4.68	1.36	1.36	0.15	0.83	0.83	-0.43
2	4	2.73	2.65	3.13	1.30	1.33	-2.28	0.79	0.81	-3.58
3	6	2.65	2.60	2.08	1.25	1.30	-4.01	0.74	0.78	-5.88
4	7	2.63	2.58	1.96	1.23	1.28	-4.25	0.73	0.77	-6.21
5	8	2.61	2.56	1.96	1.22	1.27	-4.30	0.72	0.76	-6.30
6	9	2.60	2.54	2.02	1.21	1.26	-4.25	0.71	0.76	-6.24
7	10	2.58	2.53	2.13	1.20	1.25	-4.12	0.71	0.75	-6.09
8	12	2.57	2.51	2.40	1.19	1.23	-3.76	0.70	0.74	-5.64
9	14	2.56	2.49	2.71	1.18	1.22	-3.33	0.69	0.73	-5.10
10	16	2.55	2.47	3.03	1.18	1.21	-2.88	0.69	0.72	-4.52
11	18	2.54	2.46	3.35	1.17	1.20	-2.43	0.68	0.71	-3.95
12	20	2.54	2.44	3.66	1.17	1.19	-2.00	0.68	0.70	-3.39
13	25	2.53	2.48	1.64	1.16	1.17	-1.08	0.68	0.69	-166
14	30	252	2.48	1.59	1.16	1.17	-1.16	0.67	0.68	-1.77
15	35	2.51	2.47	1.58	1.15	1.17	-1.18	0.67	068	-1.79
16	40	2.51	2.47	1.60	1.15	1.16	-1.17	0.67	0.68	-1.77
17	45	2.51	2.47	1.62	1.15	1.16	-1.13	0.67	0.68	-1.73
18	50	2.51	2.46	1.66	1.15	1.16	-1.08	0.67	0.68	-1.67
19	55	2.50	2.46	1.70	1.15	1.16	-1.03	0.66	0.67	-1.60
20	60	2.50	2.46	1.74	1.15	1.16	-0.97	0.66	0.67	-1.53
21	70	2.50	2.45	1.82	1.14	1.15	-0.85	0.66	0.67	-1.37
	| Minimum relative error |=0.15%					*|Maximum relative error|=6.30%*				

Table 5. Relative errors on calculated slopes for h=250 , h=300mm, h=350 mm

Ref	Street right-of-way L (m)	Water height h (mm)								
			250			300			350	
1	3	0.57	0.57	1.09	0.43	0.41	3.78	0.34	0.32	7.13
2	4	0.54	0.55	-2.63	0.40	0.40	-0.36	0.31	0.30	2.69
3	6	050	0.53	-5.37	0.37	0.38	-3.43	0.28	0.28	-0.61
4	7	0.49	0.52	-5.77	0.36	0.37	-3.88	0.27	0.28	-1.07
5	8	0.48	0.51	-5.88	0.35	0.36	-3.99	0.27	0.27	-1.17
6	9	0.48	0.50	-5.81	0.35	0.36	-3.90	0.26	0.27	-1.05
7	10	0.47	0.50	-5.63	0.34	0.35	-3.68	0.26	0.26	-0.80
8	12	0.46	0.49	-5.09	0.34	0.35	-3.05	0.26	0.26	-0.08
9	14	0.46	0.48	-4.43	0.33	0.34	-2.29	0.25	0.25	0.78
10	16	0.46	0.47	-3.74	0.33	0.33	-1.49	0.25	0.25	1.68
11	18	0.45	0.47	-3.05	0.33	0.33	-0.69	0.25	0.24	2.58
12	20	0.45	0.46	-2.38	0.32	0.32	0.09	0.25	0.24	3.45
13	25	0.45	0.45	-1.07	0.32	0.32	0.22	0.24	024	1.94
14	30	0.44	0.45	-1.20	032	0.32	0.07	0.24	024	1.77
15	35	0.44	0.45	-1.23	0.32	0.32	0.03	0.24	0.23	1.74
16	40	0.44	0.45	-1.21	0.31	0.31	0.06	0.24	0.23	1.77
17	45	0.44	0.44	-1.16	0.31	0.31	0.13	0.24	0.23	1.85
18	50	0.44	0.44	-1.08	0.31	0.31	0.21	0.24	0.23	1.95
19	55	0.44	0.44	-1.00	0.31	0.31	0.31	0.24	0.23	2.07
20	60	0.44	0.44	-0.91	0.31	0.31	0.42	0.24	0.23	2.19
21	70	0.44	0.44	-0.72	0.31	0.31	0.64	0.23	0.23	2.45
	/ *Minimum relative error* /=0.03%					/ *Maximum relative error* /=7.13%				

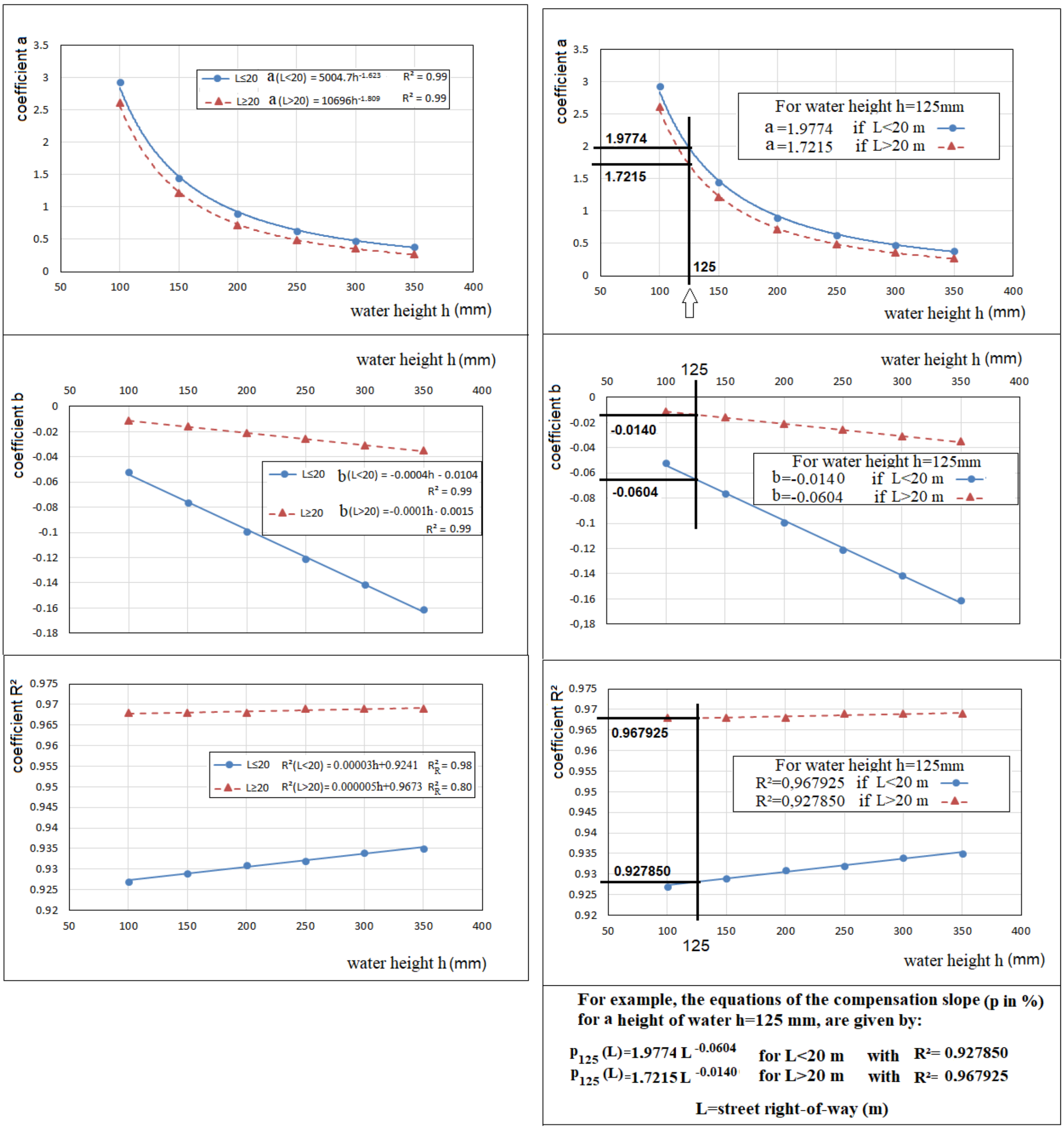

Figure 7. Coefficient a, b and R^2 depending on the height of water h (in mm)

In order to avoid erosion of unpaved roads in Lomé, we have to see to it that their slopes are limited according to slopes resulted from the equations (19a) and (19b) during the construction works. The similitude of road sediments in Lomé to that of siliceous sands leads to conclude that the resulted compensation slopes might be generalized across the whole country, Togo (Table 2, Table 3, equation (19a), equation (19b) and Figure 7). Nevertheless, complementary works are needed for a confirmation of this generalization of slopes.

6. Conclusion

To limit unpaved roads' disorders caused by water erosion, the compensation slopes of the unpaved roads are determined from the characteristics of materials (density and granular class), the geometry of roads (width and height of water), and the theory of the compensation slope. Equations and graphs are developed to deduct, no matter how wide the road and the water sheet in Lomé, the slope of these unpaved roads in order to keep them free from water erosion. The players of the design of unpaved roads and the implementation of the urbanization of Lomé possess tools of design, dimensioning and construction of unpaved roads by avoiding water erosions.

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