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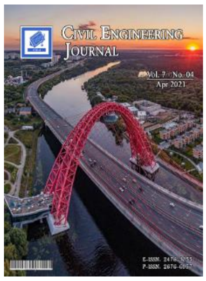

Study of Head Loss in Rapid Filtration with four River Sands

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Abstract

In this work, we studied the filtration behavior, with regard to the head loss, of four calibrated Togo Rivers sands compared to that of a reference filter sand imported from Europe. The objective is to determine the suitability of local rivers sands as filter sands for water treatment plants. The sands were successively loaded into a filtration pilot and subjected, during at least 20 hours, to the filtration of water whose turbidity was maintained at around 20 NTU. The results show that the average deviations of the head loss profiles as a function of depth, calculated in relation to the head loss recorded on the reference sand, at the same filtration time t=20h, are small and vary from 2 cm to 8 cm. In the same way, the curves of the head loss as a function of time are quite close to the one observed for the reference sand. Examination of the clogging front after 20 hours of filtration reveals that the progression is either the same or greater and reached 20 cm in depth at the same time. This study can be extended to other rivers sand samples and by varying the turbidity and the filtration rate.

Keywords: Filtration; Filter Sand; Head Loss; Clogging Front.

1. Introduction

In order to meet the many challenges related to universal access to drinking water, developing countries need to optimize the investment costs of drinking water production facilities. A better knowledge of local materials is one of the keys to taking advantage of existing potential at the territorial level. The efficient use of local materials requires a better knowledge of their characteristics and a thorough evaluation of their suitability for the intended uses. In Togo, as in most countries of the West African sub-region [1, 2], filter sand is generally imported for the needs of filter equipment in new drinking water treatment plants. In other way, if a drop of the level in the filtering beds is noted at the treatment plants, sandy materials are taken locally in the plant area to complete it, without knowing their qualifications as filtering material for a water intended for human consumption. A study of the physical and granular characteristics of Togolese river sands showed that these materials have good potential, in terms of normative values, to be used as a filter sand [3-5].

The present work aims to study the filtering capacities of Togolese four river sand samples that have been previously calibrated according to the characteristics of a reference filter sand, imported from Europe and used in a drinking water treatment plant in Togo.

From data on head losses resulting from experimentation under the same conditions, on a filtration pilot, the evolution of the head loss as a function of time and depth in the filtering beds made up of these materials was studied.

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The analysis of these data allowed a better understanding, with regard to the pressure drop, of the real filtration performances of the local materials studied, in comparison with the data recorded on the reference filter sand.

2. Experimental Approach

The river sands studied are taken from the sites of Adakpame (4ième lac), Dagué (lac Togo), Togocomé (lac Togo), Gogokondji (Mono). This choice was made to take account of the proximity of these sites to the water treatment plant of Lomé-Cacaveli, from which the reference sand of this study was taken. The location map of the maritime region of Togo with the river sands sampling sites is shown in Figure 1.

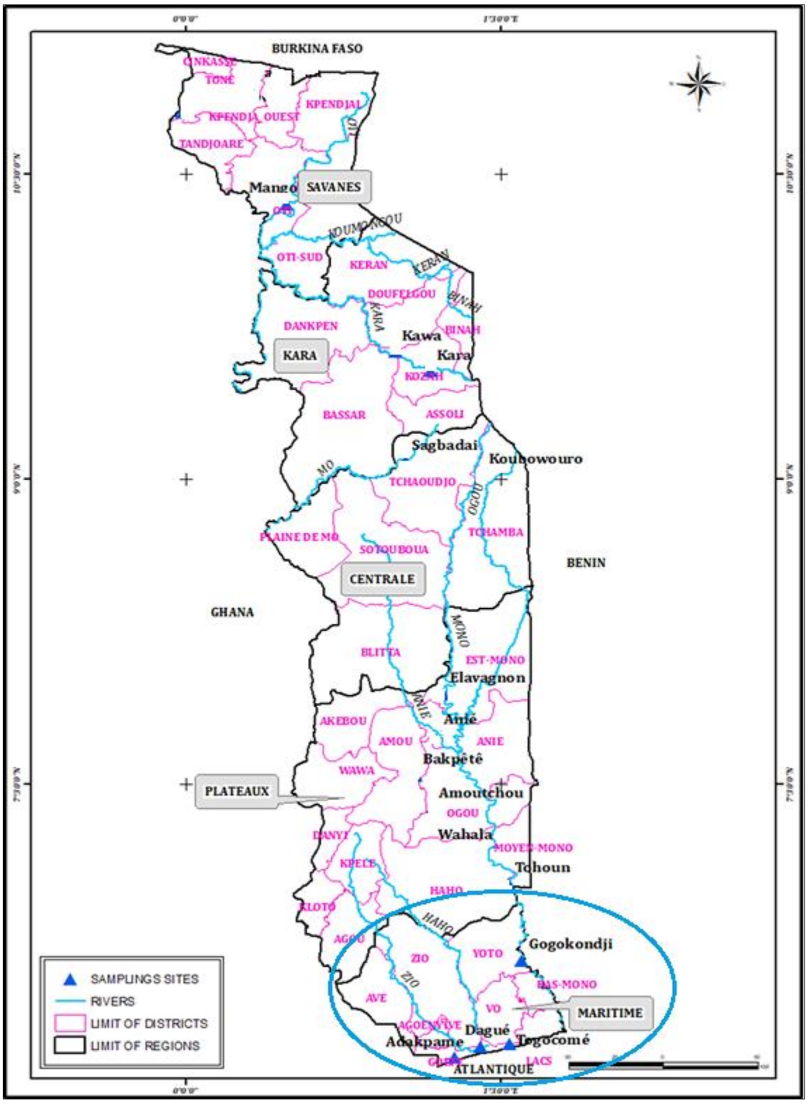

Figure 1. Location map of the river sands sampling sites

In fact, for comparison purposes, the same characteristics as those of the reference sand will be retained for the sands studied. The physical characteristics of the sands (Figure 5) are shown in the table 1 where D10 is the effective size, Cu the uniformity coefficient and P_{UT} the usable proportion of the calibrated sand in the samples.

The schematic experiment set-up of the filtration is shown in Figure 3. The main components of the installation are described below. The dimensions (diameter, height...) of the pipes and the bed are chosen to simulate a rapid filtration under the conditions of the test. The components are:

- A cylindrical PVC pressure pipe PN 10, with an internal diameter of 90 mm and a total height of 150 cm;
- A 70 cm deep bed of uniform mono-media filter sand, constituting the filtering bed ;
- Five tapping valves along the filtering bed to take raw water samples;
- A set of five piezometric tubes arranged along the bed at depths of 10, 20, 30, 40 and 55 cm for pressure drop measurements at different depths and equipped with a graduated ruler to read the water heights;

- An overflow made up for the evacuation of the excess water overlying the bed;
- A bottom tap to collect samples of filtered water;
- A peristaltic pump model YZ1515x from the manufacturer CRPUMP to supply the pilot with raw water;
- A raw water tank with a capacity of 150 litres.

Table 1. Physical characteristics of the sands [3, 6-9]

Sampling sites		Adakpame ($4^{\text{ième}}$ lac)	Dagué (lac Togo)	Togocomé (lac Togo)	Gogokondji (Mono)	Cacaveli
Bulk density		1.41	1.44	1.44	1.39	1.45
Absolute density		2.63	2.61	2.61	2.72	2.68
Porosity (%)		46%	45%	45%	49%	46%
Acid loss (%)		0.66	0.86	0.74	0.96	1.08
Friability (750 strokes %)		7.8	2.2	2.2	12.2	28.89
Friability (1500 strokes %)		12.22	4.44	4.44	22.22	46.67
Calibrating for D_{10}=1.06 mm and Cu=1.53	P_{UT} en %	10	10	8	22	-
	Theoretical and practical granular fractions (mm)	1 – 3.15	1 – 3.1	1 – 3.15	0.98 - 2	-
		1 – 3.15	1 – 3.15	1 – 3.15	1 - 2	0 – 2.5

The five samples of filter sand were successively loaded into a filtration pilot and subjected, during an operation period of at least 20 hours, to the filtration of water whose turbidity was maintained at around 20 NTU in order to have comparable results for each sample studied. The filtration rate was adjusted, under laboratory conditions, to be close to the lower threshold for rapid filtration by placing it at around 2.74 m/hour [10] because to simulate rapid filtration, the filtration rate should be between 2 and 15 m/hour. During the operation period, a series of measurements were carried out on the pressure drop at the bottom of the filter and at different depths of the bed [11]. The analysis of the treatments results carried out on the basis of the data taken from the river sand samples will enable comparisons to be made with those of the reference sand in order to draw conclusions regarding the performance of the sands under study from the point of view of head loss.

The pressure drop measurement as a function of time gives an idea of the clogging evolution in the filter. In order to measure the pressure head at different depths of the filter bed, readings were taken on the piezometric tubes fitted with graduated rulers and fixed to the wall of the filter column. The variation of the pressure heights at different depths of the filtering medium during the filtration cycle was read from the water level in the corresponding piezometric tube. The total pressure drop across and along the filter bed at different depths was obtained from the difference in the corresponding pressure readings.

The data collected on the pressure drop allow to represent the evolution of the pressure drop as a function of time and as a function of the different depths of the filter bed. An assessment of the variation differences with the reference sand will also be made in order to draw conclusions on the behaviour of the materials studied, under the same filtration conditions.

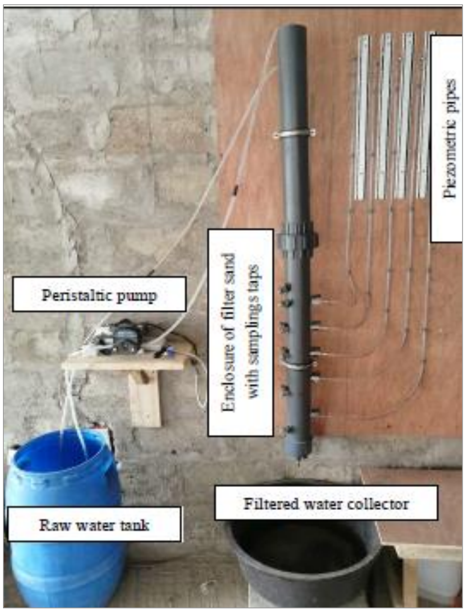

Figure 2. Filtration experiment set-up

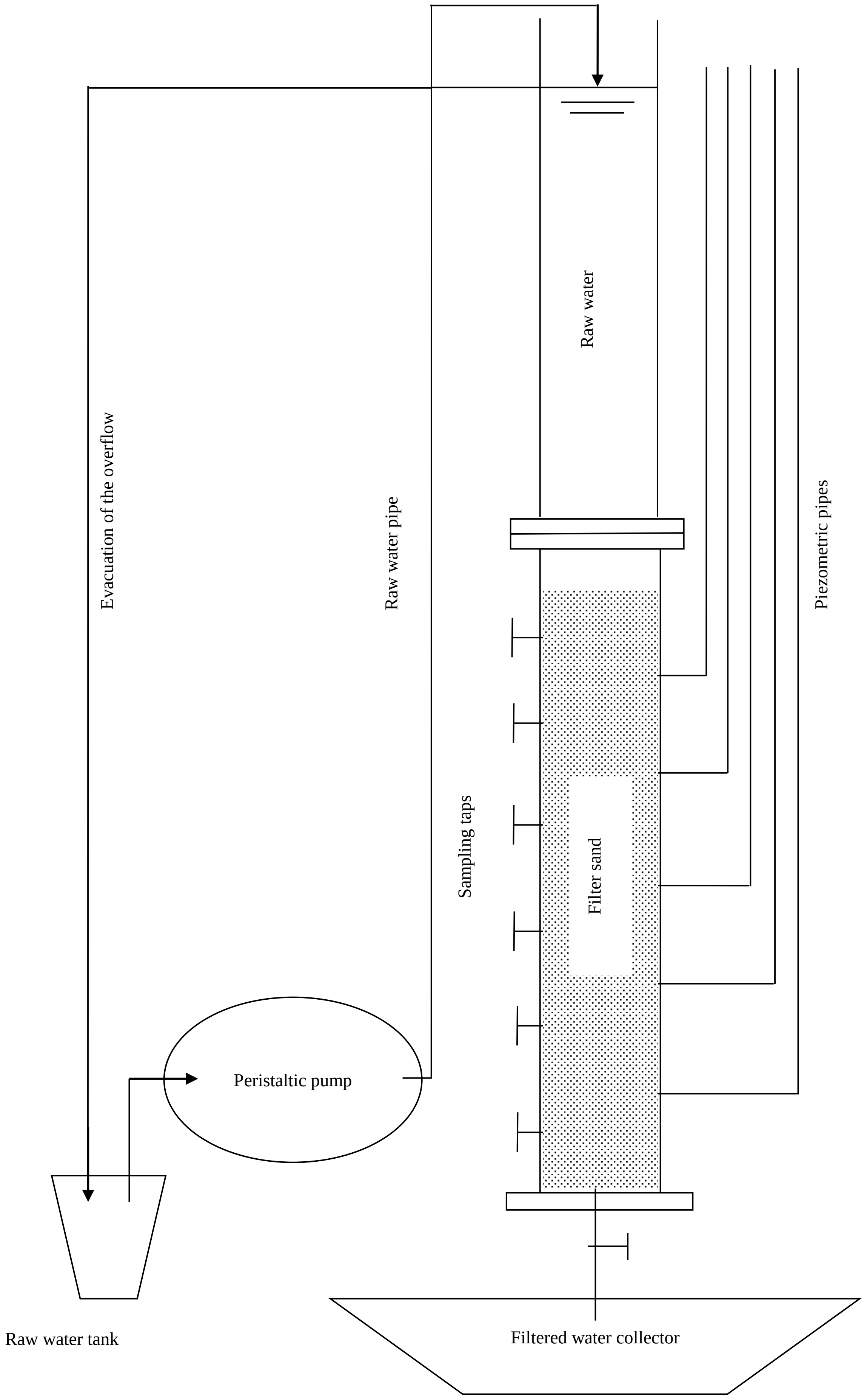

Figure 3. Schematic filtration experiment set-up

Figure 4. Turbidimeter

Adakpame Dagué Togocomé Gogokondji Cacaveli

Figure 5. Rivers sands calibrated samples

Specifically, the study of the pressure drop evolution as a function of time will allow to deduce, from the regression functions, the YVES [12] and DEGREMONT [13] models.

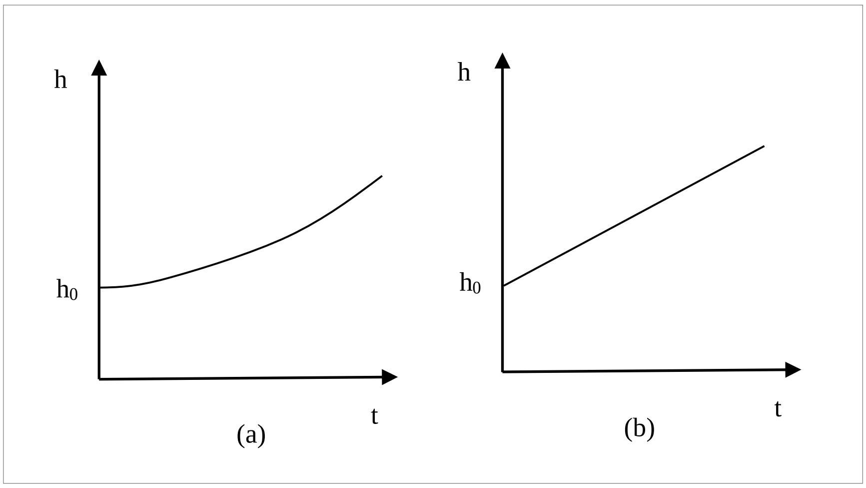

Figure 6. Evolution of the head loss over time. (a) Degrémont model; and (b) Ives model

These two models of the pressure loss (h) as a function of time (t) are interesting for interpreting the pressure loss curves evolution encountered in practice. Above all, they make it possible to evaluate the time taken for a given filter to reach its maximum permissible pressure drop.

With the pressure loss data collected at different depths, the pressure gradient dp/dz is determined as a function of time for the different layers of the filter bed. The study of the pressure drop profiles evolution allows to follow the clogging of the bed. This diagram will thus allow a comparative analysis of the evolution of the clogging front inside the different beds, under the filtration conditions of our work.

3. Results and Discussion

The head loss variation, as a function of depth, based on interpolated data, for a filtration time of 20 hours, for the five samples, is as shown on the graph in Figure 7.

The analysis of this graph, carried out at the same filtration time t, for all the sand samples, confirms the uniformity of the variation of the pressure losses in the beds with slight deviations from the reference sand. Table 2 shows these deviations as a function of depth as well as the average deviation over 55 cm of filter bed.

It is noted that, generally, the average deviations of the head loss profiles as a function of depth, calculated in relation to the head loss recorded on the reference sand, at the same time, are small and vary from 2 cm for the Dagué sand to 8 cm for the 4th Lake (Adakpame) sand. We can deduct from this that the behavior, under the filtration conditions of our tests, of the river sands, after 20 hours of operation of the pilot, is close to that of the reference sand.

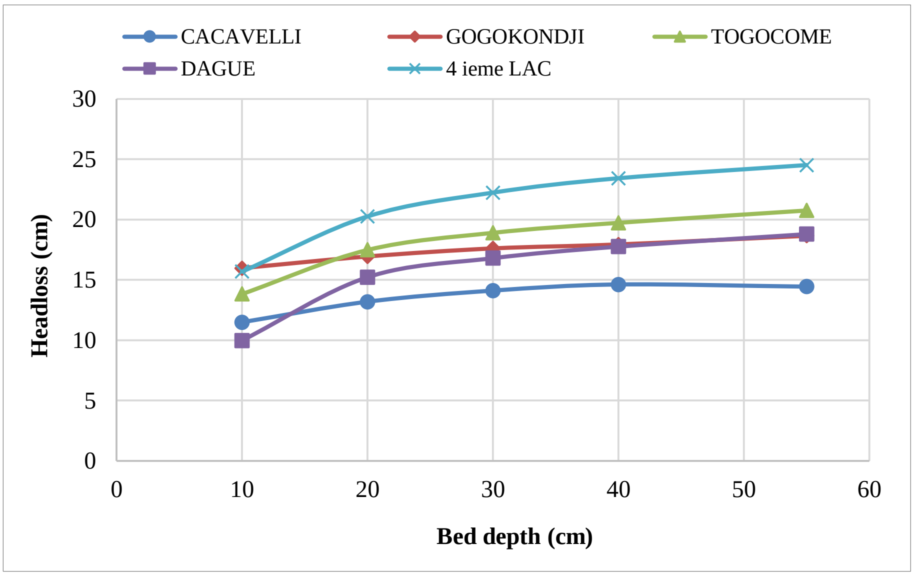

Figure 7. Evolution of the head loss over the bed depth

Table 2. Head loss gap (Δh) as a function of depths at time t=20h

Bed depth (cm)	Headloss (cm)								
	Cacaveli	Gogokondji		Togocomé		Dagué		4^{ieme} Lac	
	Δh	$Δh_1$	$Δh_1$-Δh	Δh2	$Δh_2$-Δh	Δh3	$Δh_3$-Δh	Δh4	$Δh_4$-Δh
10	11.49	15.97	4.48	13.84	2.35	9.98	-1.51	15.69	4.20
20	13.19	16.94	3.75	17.49	4.3	15.22	2.03	20.26	7.07
30	14.11	17.61	3.5	18.91	4.8	16.8	2.69	22.23	8.12
40	14.62	17.94	3.32	19.74	5.12	17.76	3.14	23.42	8.80
55	14.44	18.66	4.22	20.76	6.32	18.79	4.35	24.51	10.07
Average gap (cm)		4		5		2		8	

On the basis of the strong correlations observed for the pressure losses variation according to depth, the pressure losses at the bottom of the bed, at a depth of 70 cm, which could not be measured during the tests, were calculated from mathematical trend curve models, because the filtration pilot used did not have support gravel at its bottom to allow the installation of a piezometer at this depth. The curves of variations in pressure losses as a function of time for the 55 cm depths (data measured during the tests) and the bottom of the beds are shown in Figures 8 and 9 [14].

The curves confirm the existence of a linear relationship at the beginning of the filtration cycle (YVES model) [12], as can be seen here in the two figures between 0 and 5h and then the pressure drop increases exponentially (DEGREMONT model) [13]. The expressions of the linear (YVES) and exponential (DEGREMONT) type models, obtained from the data and curves in Figure 9 for total head losses in beds, are shown in Table 3 with the corresponding R^2 determination coefficients.

These expressions show, when analyzing the values of the determination coefficients, that the exponential type function best reflects the head loss variation as a function of time, under the adopted filtration conditions. In order to compare the behavior of the different filtering sands under study as a function of time, these models were used to calculate the head losses values at the times 0h, 5h, 10h, 15h and 20h for the different samples, as well as the deviations noted with the values of the reference filtering sand. The results are presented in Table 4.

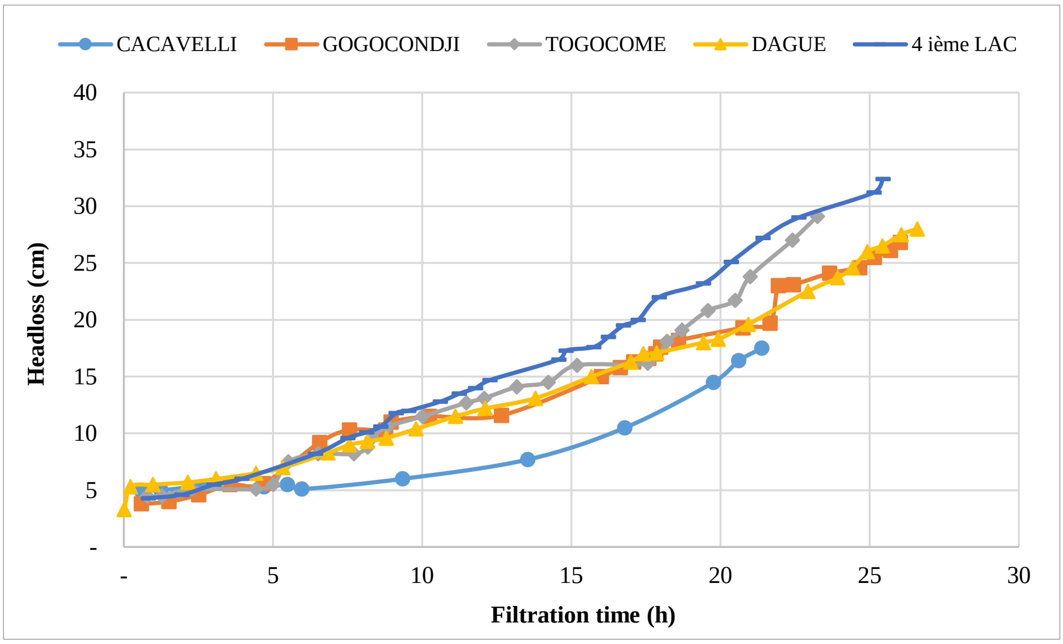

Figure 8. Head loss variation as a function of time (55 cm depth)

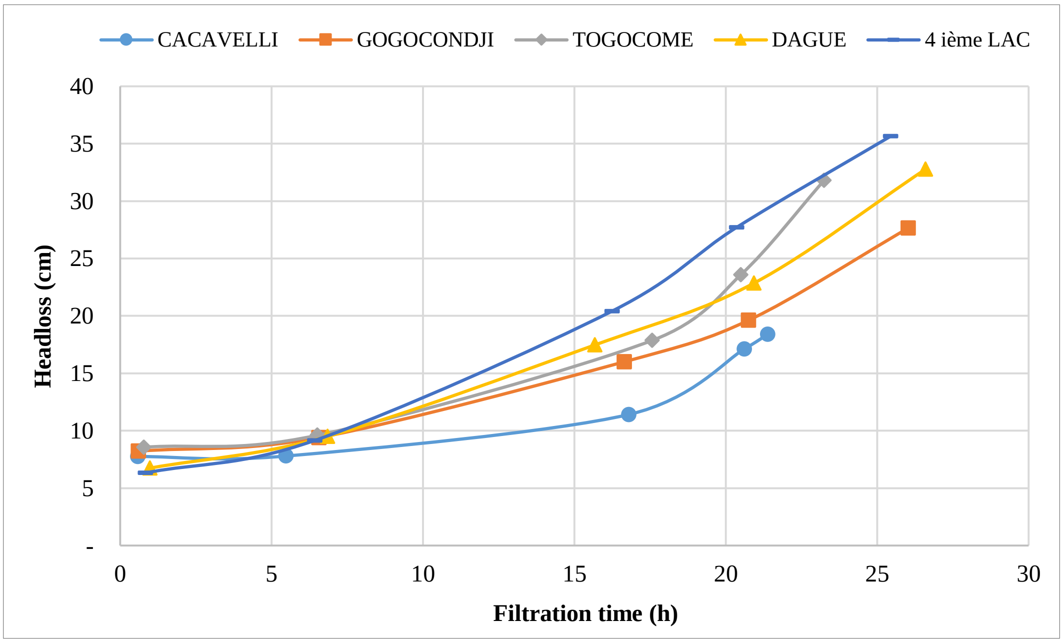

Figure 9. Head loss variation as a function of time (70 cm depth)

Table 3. Expressions of total head loss as a function of time (filtration with V=2,74 m/h, 70 cm of bed depth and D10 = 1,06 mm)

Sites	YVES Model		DEGREMONT Model	
	Δh = f(t)	**R²**	**Δh = f(t)**	**R²**
Cacaveli	$\Delta h = 0{,}4944t + 6{,}0854$	0.8479	$\Delta h = 6{,}7982e^{0{,}0417t}$	0.9006
Gogokondji	$\Delta h = 0{,}7356t + 5{,}7932$	0.9249	$\Delta h = 7{,}3938e^{0{,}0484t}$	0.9832
Togocomé	$\Delta h = 0{,}9468t + 5{,}2898$	0.8744	$\Delta h = 7{,}3377e^{0{,}0575t}$	0.9575
Dagué	$\Delta h = 0{,}9915t + 3{,}777$	0.9586	$\Delta h = 6{,}3341e^{0{,}062t}$	0.9985
4 ième Lac	$\Delta h = 1{,}2058t + 3{,}1307$	0.973	$\Delta h = 5{,}955e^{0{,}0728t}$	0.995

Table 4. Head loss gap (Δh) as a function of depths

Time (h)	Head loss Δh (cm)								
	Cacaveli	Gogokondji		Togocomé		Dagué		4 ieme Lac	
	Δh	Δh_1-Δh		Δh_2-Δh		Δh_3-Δh		Δh_4-Δh	
0	6.80	7.39	0.60	7.34	0.54	6.33	-0.46	5.96	-0.84
5	8.37	9.42	1.04	9.78	1.41	8.64	0.26	20.26	11.89
10	10.32	12.00	1.68	13.04	2.72	11.77	1.46	22.23	11.91
15	12.71	15.28	2.57	17.38	4.68	16.05	3.35	23.42	10.71
20	15.65	19.47	3.81	23.17	7.52	21.89	6.24	24.51	8.86
Average gap (cm)		1.94		3.37		2.17		8.51	

Analysis of the data in Table 4, in relation to the graphs in Figures 8 and 9, reveals the following:

- The curves of head losses evolution versus time, for the Togolese river sand samples, are quite close to the one observed for the reference sand over an operating time of more than 20 hours, under the conditions of the pilot filtration test with an average difference ranging from 1.94 cm to 8.51 cm over the period; these differences have evolved with the evolution of the filtration test and the growth of the head losses over time;
- The filter sand obtained from the Gogokondji site on the Mono River shows the lowest average deviation, followed by samples from the Dagué and Togocomé sites on Lake Togo and finally that of the 4th lake in Adakpame;
- The head loss values observed at the start of the pilot filtration are fairly close and between 5.96 cm and 7.39 cm (with 6.80 cm for the reference sand), with a mean of 6.76 cm and a standard deviation of around 0.63; the dispersion is greater towards the end of the operation;
- The curves obtained from the river sand samples studied are above that of the reference sand, except for the Dagué and 4th Lake samples for which lower values are recorded at start-up and during about 4 hours of filtration. This can be explained in part by the finer grain size of these samples which resulted in slightly higher pressure drops during the filtration.

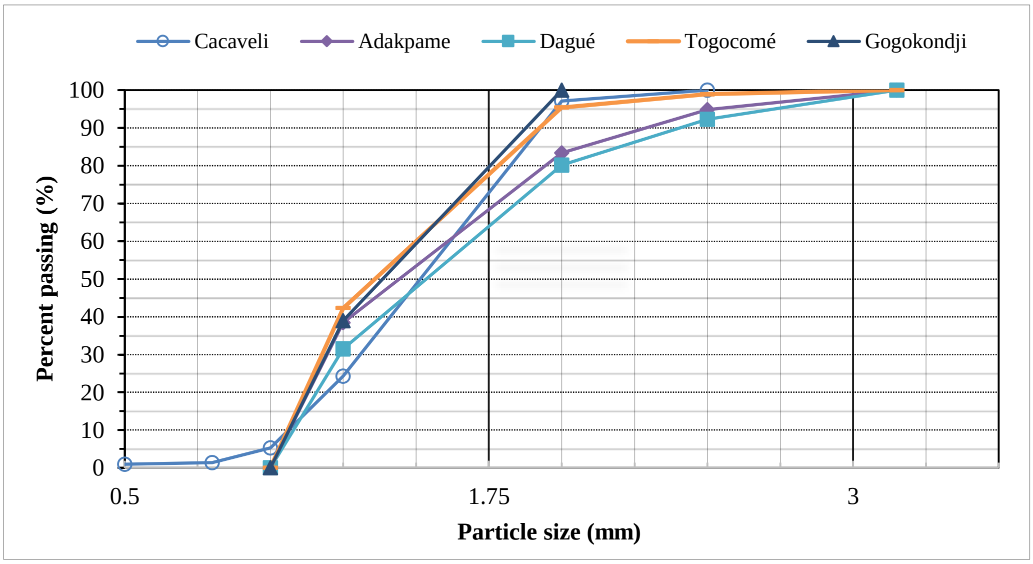

Figure 10. Grain size distribution curves of the calibrated sands for filtration test

In fact, although the river sands studied were calibrated to have an effective diameter and a uniformity coefficient in line with the reference sand, the particle size compositions obtained after calibration are not strictly similar to those of the reference sand, as shown in Figures 5 and 10. In general, the sizing specifications of sands are represented in the form of a spindle within which several grading curves can be inscribed which comply with the target specification. Thus, it can be noted on the graph above that the proportion of fine elements, evaluated here by the passers-by with a 1.25 mm sieve, is higher for the river sands studied (between 31.49 and 42.3%) against 24.26% for the reference sand. The presence, in higher quantities, of these fine elements between the grains can create obstacles to the interstitial flow of water and cause the observed differences in head loss [15]. Finally, it should be noted that the reference sand, which is a commercial sand produced in an industrial environment with advanced technological processes for sieving, could present a better calibration than the river filtering sands studied, whose calibration was carried out under laboratory conditions;

- Generally, the small differences observed between the curves can be explained essentially by the relative variation in filtration during the tests (filtration rate, raw water turbidity and temperature) and the inhomogeneity of the filter beds, from one sample to another [16].

Lindquist diagrams show the distribution of material retained in the gravel pack as a function of depth [9, 17-20]. In order to be able to carry out an appropriate analysis, the data for the Lindquist diagram for the five samples at the same time t=20h was calculated by interpolating the test results. This diagram is shown in Figure 11.

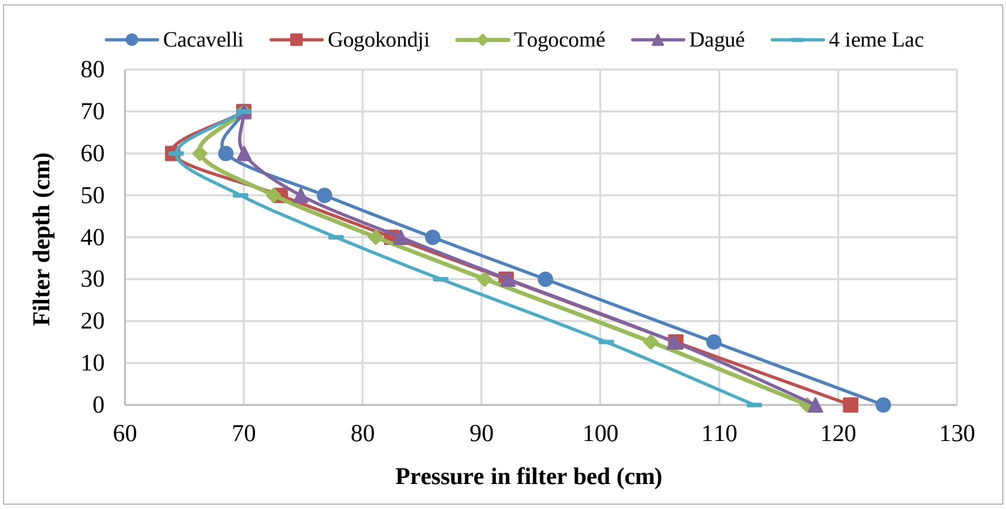

Figure 11. Lindquist diagram at t=20h

Examination of this diagram also reveals important information on the comparative evolution of clogging fronts in filter beds. Indeed, it can be noted that after 20 hours of filtration, the clogging front progressions were already identical to those recorded at the end of the operation and presented above. It is the same for the reference and Gogokondji filter sand and varies from 0 cm on the surface of the bed to 10 cm in depth. For the samples from the other sites, the progression of the front was greater and reached 20 cm in depth at the same time. This conclusion supports the previous observation on the similarity, under the filtration conditions of our tests, of the capabilities of the Gogokondji filter sand with those of the reference filter sand.

4. Conclusion

The filtering capacities study of the samples, subjected to the pilot filtration test, showed that the river sands, calibrated according to the properties of the reference filter sand, have curves of head loss variation versus depth that follow the same function as the reference sand. The average deviations of the head loss profiles as a function of depth, calculated in relation to the head loss recorded on the reference sand, at the same filtration time t=20h, are small and vary from 2 cm for the Dagué sand to 8 cm for the 4th lake sand. In the same way, the curves of evolution of the head loss as a function of time, for the river sand samples under study, are quite close to the one observed for the reference sand over an operating time of more than 20h, with an average deviation ranging from 1.94 to 8.51 cm over the period. Examination of the clogging front after 20 hours of filtration reveals that the progression of the clogging front is the same for the reference filter sand and the Gogokondji filter sand, varying from 0 cm on the surface of the bed to 10 cm deep. For the samples from the other sites, the progression of the front was greater and reached 20 cm in depth at the same time.

In conclusion, it can be noted that, notwithstanding the small deviations observed on certain parameters related to the evolution of the head loss as a function of time and depth, the calibrated river sands of Gogokondji, Togocomé, Dagué and 4th Lake (Adakpame) showed, during the filtration test, a behaviour similar to that of the reference filter sand of Cacaveli, under the filtration conditions of our work. For a better knowledge of these materials, the study can be extended to other rivers sand samples and by varying the turbidity of the raw water, the bed depth and the filtration rate.

5. Declarations

5.1. Author Contributions

Conceptualization, K.E.A., Y.M.X.D.A., and I.P.; writing—original draft preparation, K.E.A., Y.M.X.D.A., and I.P.; writing—review and editing, K.E.A., Y.M.X.D.A., and I.P. All authors have read and agreed to the published version of the manuscript.

5.2. Data Availability Statement

The data presented in this study are available in article.

5.3. Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

5.4. Conflicts of Interest

The authors declare no conflict of interest.

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