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Assessment of togolese rivers sands potential as filter sand for drinking water plants

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Abstract

In this work, the physical properties of river sands, commonly used in construction in Togo, were studied in order to assess their potential as filter sand for drinking water plants. Samples from 17 sites throughout the five Togolese administrative regions are subjected to the tests of sieve analysis, density, porosity, mass loss at acid and friability. Results analysis reveals that sands absolute density, bulk density and porosity are generally suitable to the standard specifications. 88% of the samples show good acid solubility; 71% have very good friability and 29% have good or poor friability. The size distribution properties of these samples, evaluated by the effective size (D_{10}) and the uniformity coefficient (C_u), do not allow them to be used, in their natural state, as rapid filtration sand without tailoring to the desired size. For an effective size of 1 mm and a uniformity coefficient of 1,5 for example, the usable proportions of theses natural sands vary from 6% to 28%. For the same uniformity coefficient and an effective size of 0,6 mm, the usable proportions are more important and vary from 10% to 56%.

Keywords: River sand, filter sand, drinking water, size distribution, usable proportion.

Introduction

The Sustainable Development Goals (SDGs), set by the international community, for universal access to drinking water by 2030, require developing countries to make major efforts in innovation in order to optimise the costs of drinking water production facilities, given the huge investments needed to stay on course. One of the keys to meet this major challenge will be to make better use of the many opportunities offered by local materials. However, the efficient use of these 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, filter sand is generally imported for the needs of filter equipment in new drinking water treatment plants.

The purpose of this study is to assess the suitability, as filter sand, of river sands commonly used in Togo for use in drinking water treatment plants. For this purpose, river sand samples were taken from 17 sites on Togolese territory and subjected to identification tests. The analysis of the results of these tests, with regard to the current standards for the qualification of filter sands, will help to enlighten the actors of the water sector in Togo on the aptitudes of local river sands as a filtering material.

Materials and methods

Study framework: Togo is a country in West Africa located between the 6th and 11th degrees north latitude and 0 and 1.6 degrees east longitude. The country is divided into five (05) administrative regions which are, from south to north: the “Maritime” region, the “Plateaux” region, the “Centrale” region, the “Kara” region and the “Savanes” region.

This study focused on river sands taken from sites that are located along the main rivers of the Togolese territory and their tributaries. The location of the sampling sites in the five administrative regions is presented on the map in Figure-1 with the data from the Table-1. Apart from these samples, for comparison purposes, a reference material, which is the filter sand used by the “Société Togolaise des Eaux” on the Cacaveli treatment plant which supplies the city of Lomé, the capital of Togo, was used. This sand, imported from France, was produced in the EQIOM Aggregates plant in Saint-Eloi and is supposed to comply with the NF 12-904 standard: "Products used for the treatment of water intended for human consumption: quartz sand and gravel"[1].

Physical characterization of the river sands: All the sand samples under study were subjected to the following tests: i. particle size analysis according to standard NF X 45.401[2]; ii. the measurement of apparent and absolute densities according to the NF X 45.401 standard[2]; iii. acid solubility with hydrochloric acid according to standard NF X 45.401[2]; iv. friability according to standard[3-4].

The results of the particle size analysis made it possible to determine the following parameters: i. the diameters D_{10} and D_{60} allowing respectively 10% and 60% of the grains to pass through; ii. the uniformity coefficient C_u given by[1]:

$$C_u = \frac{D_{60}}{D_{10}} \quad (1)$$

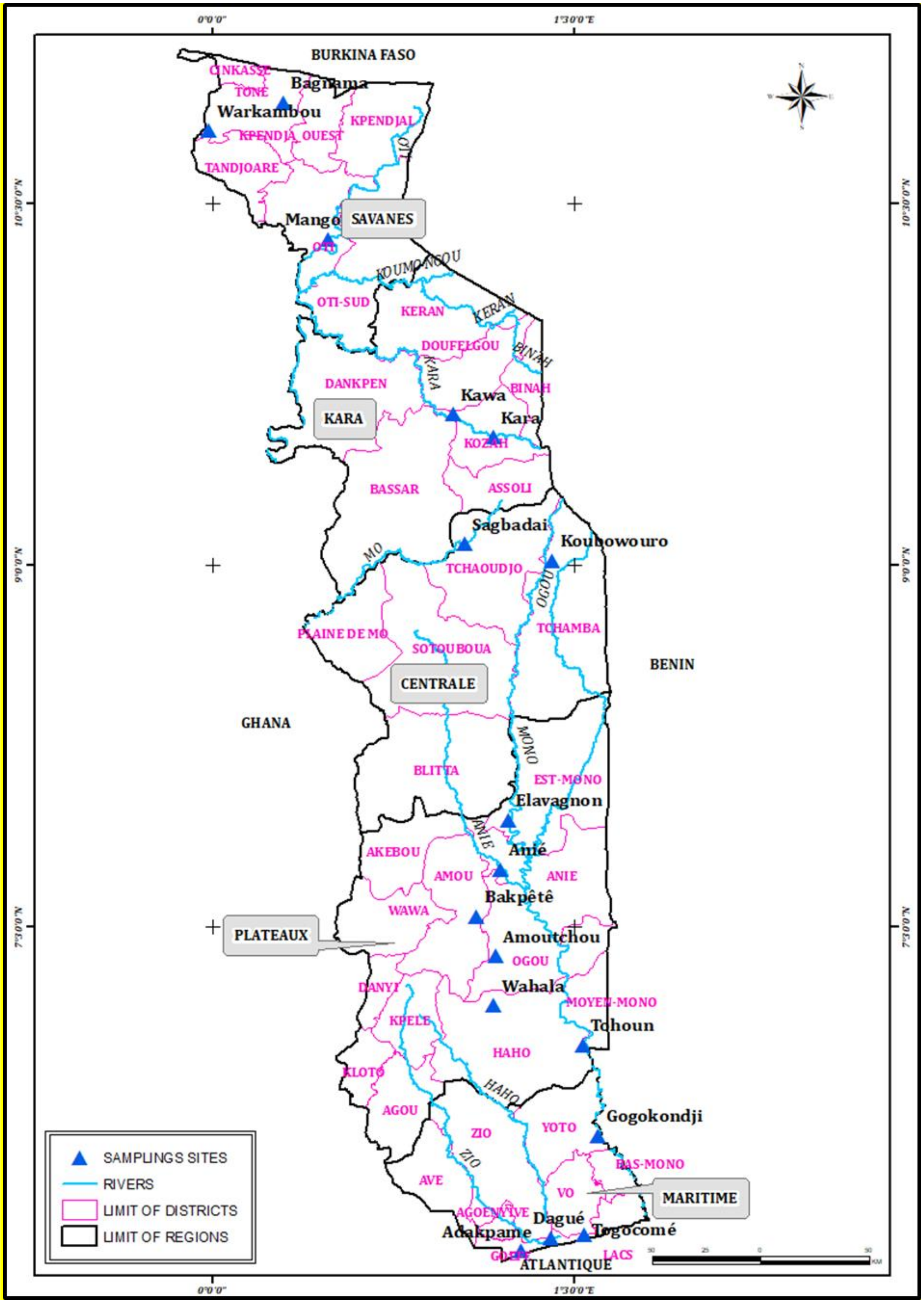

Figure-1: Location map of the river sands sampling sites.

Table-1: Location of the sampling sites.

Region	Sampling sites	Longitude	Latitude
Maritime	Adakpame (4ième lac)	1,27874	6,158644
	Dagué (lac Togo)	1,402583	6,212584
	Togocomé (lac Togo)	1,540506	6,223745
	Gogokondji (Mono)	1.601323	6.635311
Plateaux	Amoutchou (Ogou)	1,173936	7,381468
	Bakpêtê (Amou)	1,095463	7,54475
	Anié (Anié)	1,196844	7,740366
	Elavagnon (Mono)	1,22816	7,943952
	Wahala (Wahala)	1,165317	7,175133
	Tohoun (Mono)	1,536831	7,01305
Centrale	Sokodé (Sagbadai)	1,046543	9,090273
	Tchamba Koubowouro (Mono)	1,41	9,02
Kara	Kara (Kara)	1,164174	9,532039
	Kawa (Kawa)	0,999517	9,626883
Savanes	Mango (Oti)	0,482254	10,351875
	Warkambou (Warkambou)	-0,014817	10,802083
	Korbongou (Bagnama)	0,293604	10,918502

The densities of the materials were calculated by applying the following formula:

$$d = \frac{\rho_g}{\rho_e} \quad (2)$$

With d: the density of the materials; ρ_g: the density of the bulk or compact material (g /cm^3) and ρ_e: the density of water which is 1g/cm^3. The porosity has been deduced from the values of apparent and absolute densities.

The Acid Solubility (AS) was calculated at the end of the test by the expression[1]:

$$AS = \frac{P_E - P_1}{P_1} x100 \quad (3)$$

Where P_E is the initial mass of the sample and P_1 is the mass of the sample after contact with the acid solution.

Friability, which represents the percentage loss after crushing, is calculated with X representing the percentage of material smaller than the initial "effective size" after crushing, by the expression:

$$\text{Friability (\%)} = \frac{10}{9}(X - 10) \quad (4)$$

Filter sands qualification criteria: The assessment of the results is made according to the criteria presented as follows: i. the maximum value of the uniformity coefficient of the filter sands, for use in rapid filtration of drinking water, must be between 1.5 and 1.8[2-3]; ii. the bulk density of filter sands is generally between 1.4 and 1.7 and the absolute density between 2.5 and 2.8[2]; iii. the porosity must be between 40% and 60%; iv. the acid solubility must be less than 2% for a granular material to be suitable for water filtration[4]; v. the friability of granular materials is assessed according to the criteria presented in the following table, depending on the number of strokes applied in the test[4].

Table-2: Filter sands friability assessment[3].

Characteristic	750-stroke test	1500-stroke test
Very good	6 to 10 %	15 to 20 %
Good	10 to 15 %	20 to 25 %
Poor material	15 to 20 %	25 to 35 %
To be absolutely rejected	More than 20%	More than 35%

Filter sand calibration methodology: Sands, like all other filter materials, do not, in their raw state, meet the required granulometric specifications, particularly those relating to effective size and uniformity coefficient. They must be graded to be adapted to the specific need for the intended use. The methodology for determining, for a given specification, the dimensions below and above which the sands must be sized is set out as follows.

According to GM Fair, JC Geyer and D Okun, if we consider as and that does not meet the required specifications, it nevertheless has a usable proportion P_{UT}, a fine fraction P_{FINE} and a coarse fraction P_{COARSE}[5]. Thus, we have:

$$P_{UT} + P_{FINE} + P_{COARSE} = 100 \quad (5)$$

For raw sand, P_{BR10} and P_{BR60} are defined as the percentages of raw sand whose sizes are respectively smaller than the specification diameters for P_{10} and P_{60}. The total proportion of usable sand is:

$$P_{UT} = 2(P_{BR60} - P_{BR10}) \quad (6)$$

The percentage of raw sand that is too fine in diameter is:

$$P_{FINE} = P_{BR10} - 0{,}1P_{UT} = P_{BR10} - 2(P_{BR60} - P_{BR10}) \quad (7)$$

The percentage of raw sand that is too coarse is the remaining portion of equation (5).

Results and discussion

Study of the decisive physical parameters: The physical parameters qualified as decisive are those whose non-compliance with the standards leads to the systematic rejection of the natural material. These are bulk and absolute densities, porosity, acid solubility and friability. The results of the related tests, carried out on the 17 samples as well as the control sand, are presented in Table-3.

Table-3: Physical characteristics of the sands.

Regions	Sampling sites	BD	AD	PO (%)	AS (%)	FR750 (%)	FR1500 (%)
Maritime	Adakpame (4ième lac)	1,41	2,63	46%	0,66	7,80	12,22
	Dagué (lac Togo)	1,44	2,61	45%	0,86	2,20	4,44
	Togocomé (lac Togo)	1,44	2,61	14%	0,74	2,20	4,44
	Gogokondji (Mono)	1,39	2,72	49%	0,96	12,20	22,22
Plateaux	Amoutchou (Ogou)	1,64	2,73	40%	0,68	6,67	11,11
	Bakpêtê (Amou)	1,57	2,73	42%	1,16	10,00	17,78
	Anié (Anié)	1,58	2,73	12%	1,78	10,00	18,89
	Elavagnon (Mono)	1,54	2,73	44%	1,24	4,44	10
	Wahala (Wahala)	1,69	2,73	38%	2,5	4,40	7,78
	Tohoun (Mono)	1,57	2,73	42%	1,28	14,44	26,67
Centrale	Sokodé (Sagbadai)	1,32	2,61	49%	0,66	3,33	4,44
	Tchamba (Mono)	1,48	2,68	45%	1,2	5,56	11,11
Kara	Kara (Kara)	1,57	2,80	45%	2,2	7,78	14,44
	Kawa (Kawa)	1,68	2,73	38%	0,48	15,60	22,22
Savanes	Mango (Oti)	1,51	2,61	42%	1,12	10,00	18,89
	Warkambou (Warkambou)	1,54	2,61	41%	1,28	13,30	22,22
	Korbongou (Bagnama)	1,45	2,61	44%	1,86	15,60	23,33
	Cacaveli (EQIOM sand)	1,45	2,68	46%	1,08	28,89	46,67

BD=Bulk Density; AD=Absolute Density; PO=Porosity; AS=Acid Solubility; FR750=Friability 750-stroke; FR1500 = Friability 1500-stroke;

The representation of the various physical characteristics studied, in relation to the normative criteria, is presented on the graphs of the Figures-2 to 7. The normative values of the parameters are indicated by red vertical lines on the graphs.

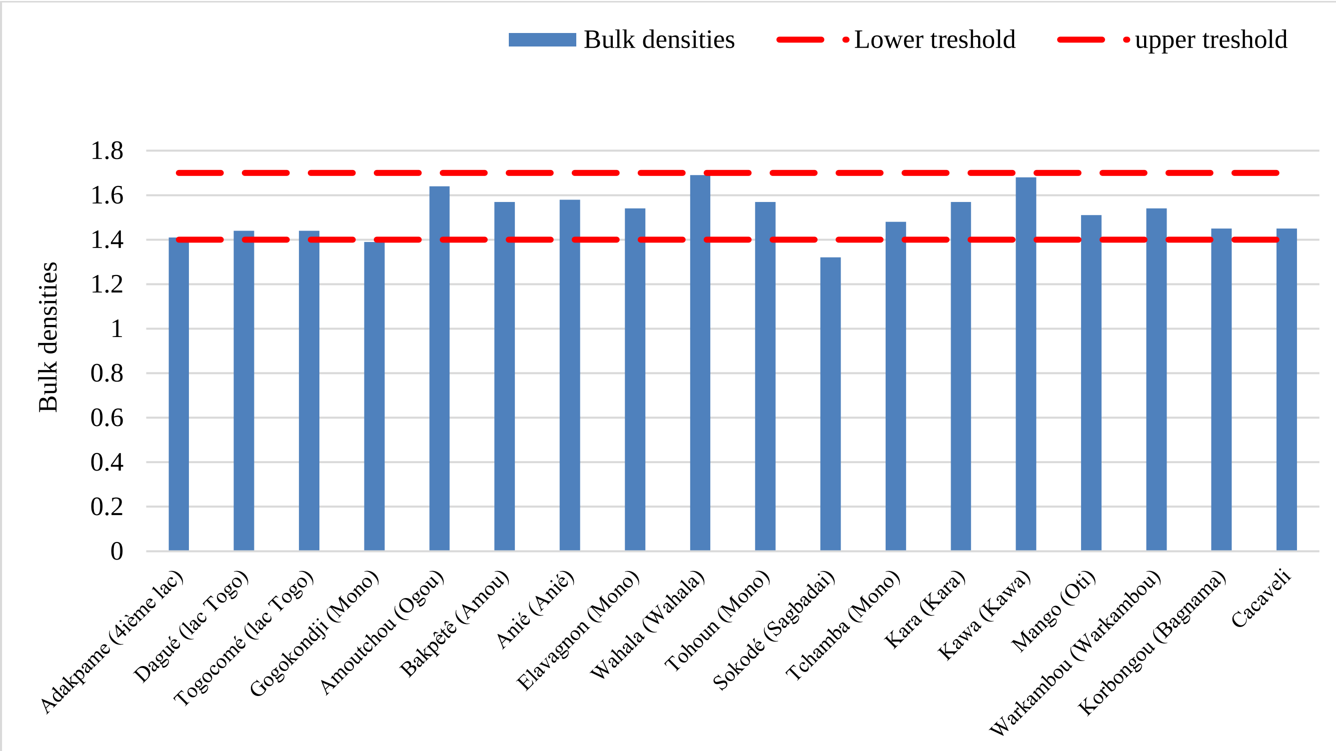

Figure-2: Bulk densities of samples in relation to normative values.

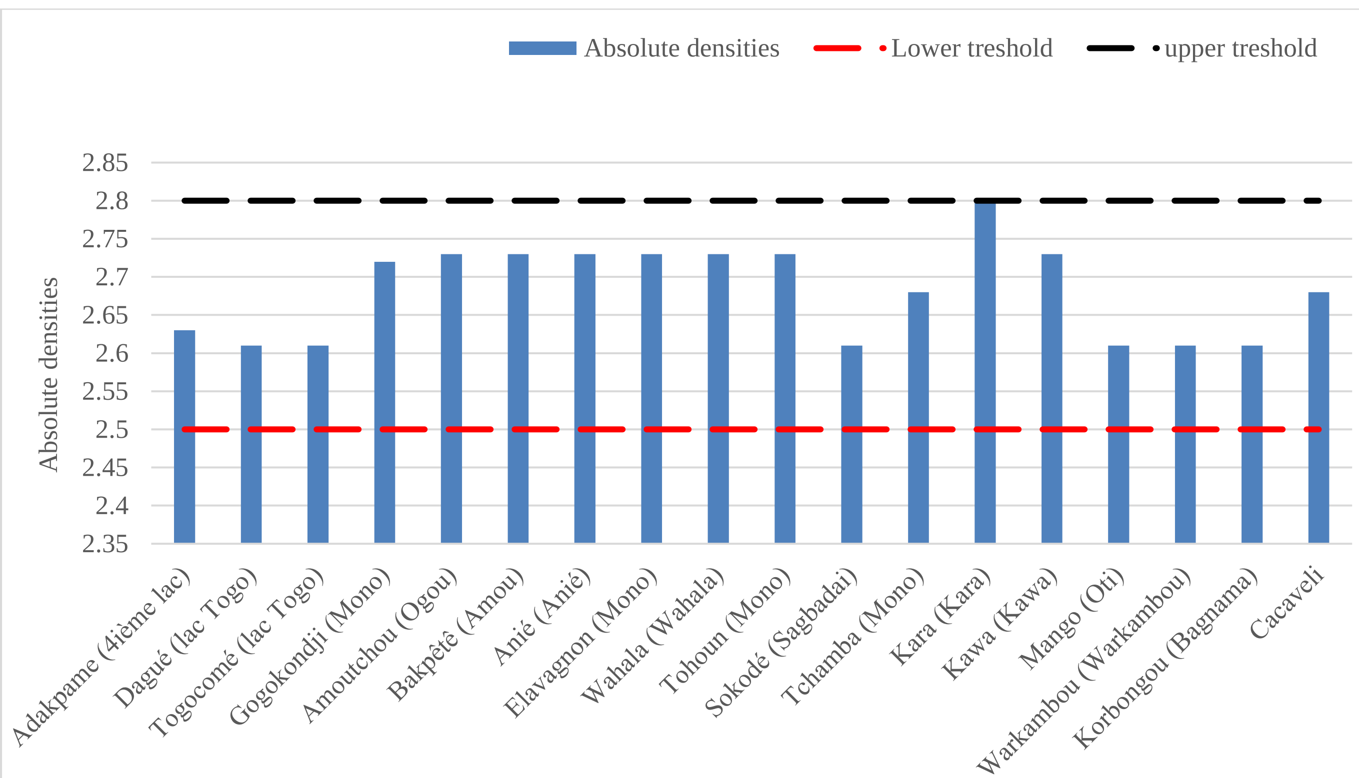

Figure-3: Absolute densities of samples in relation to normative values.

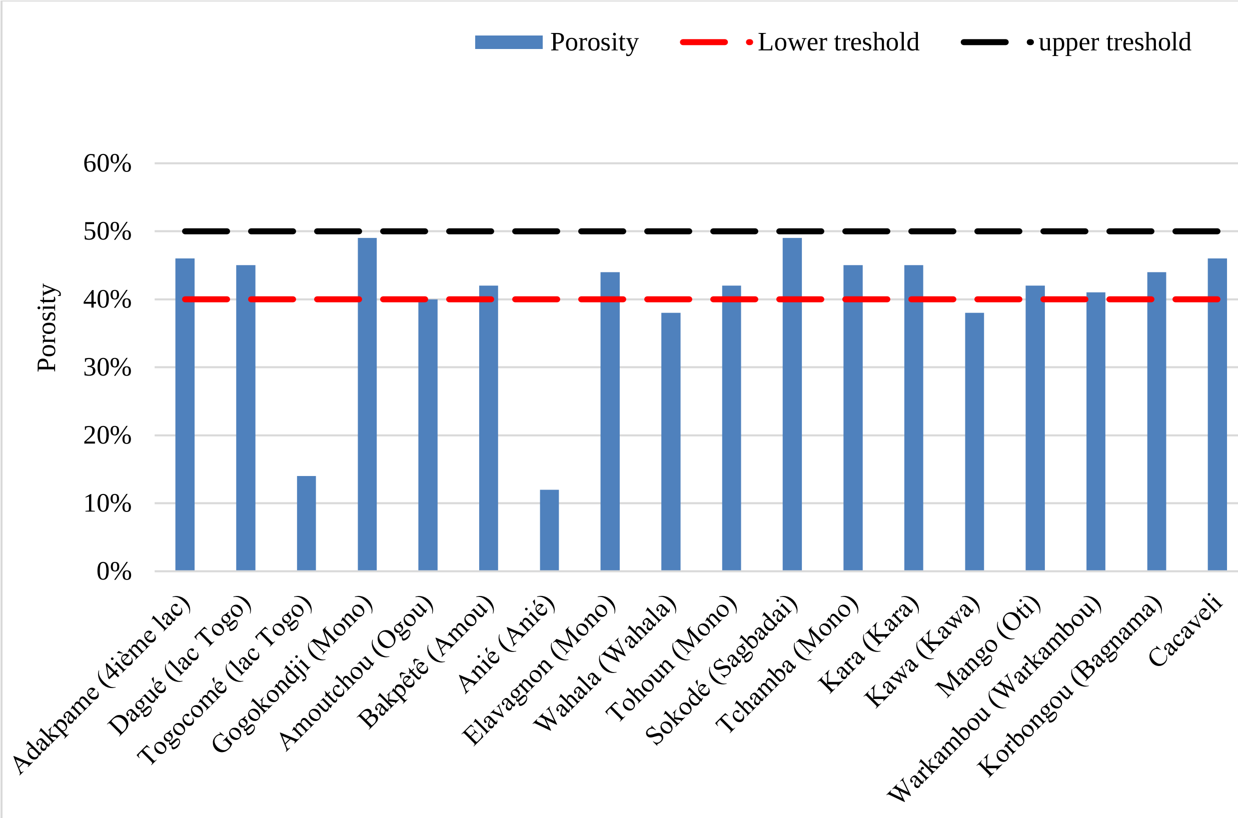

Figure-4: Porosity of samples compared to normative values.

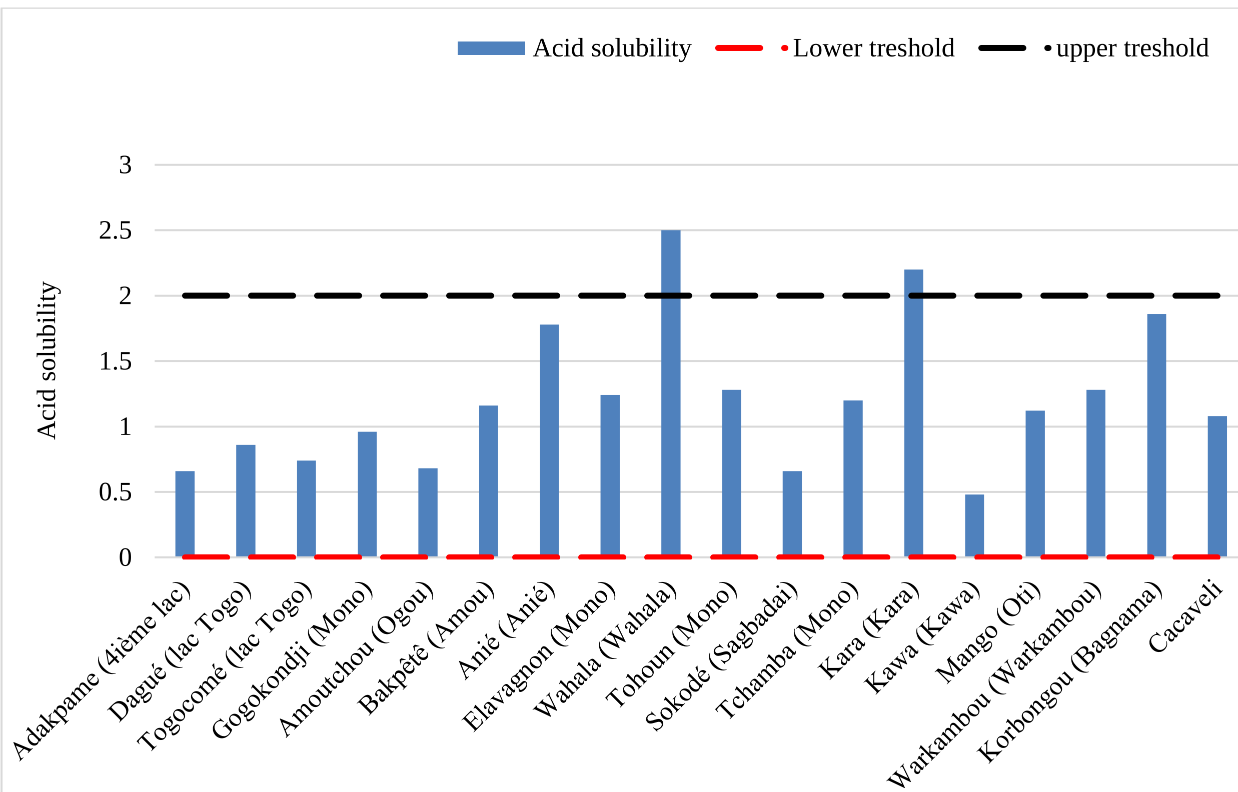

Figure-5: Acid solubility of samples in relation to the normative value.

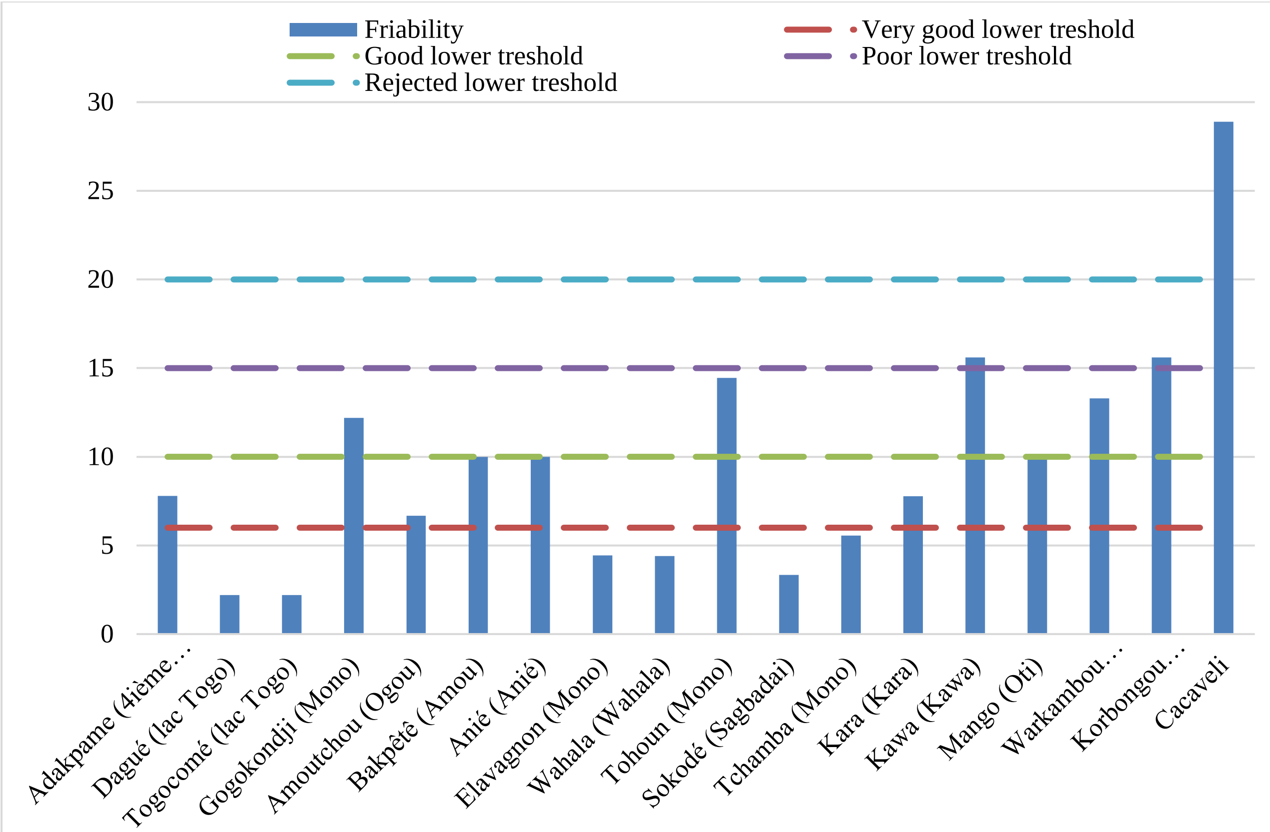

Figure-6: 750-stroke friabilities of the samples with respect to the normative values.

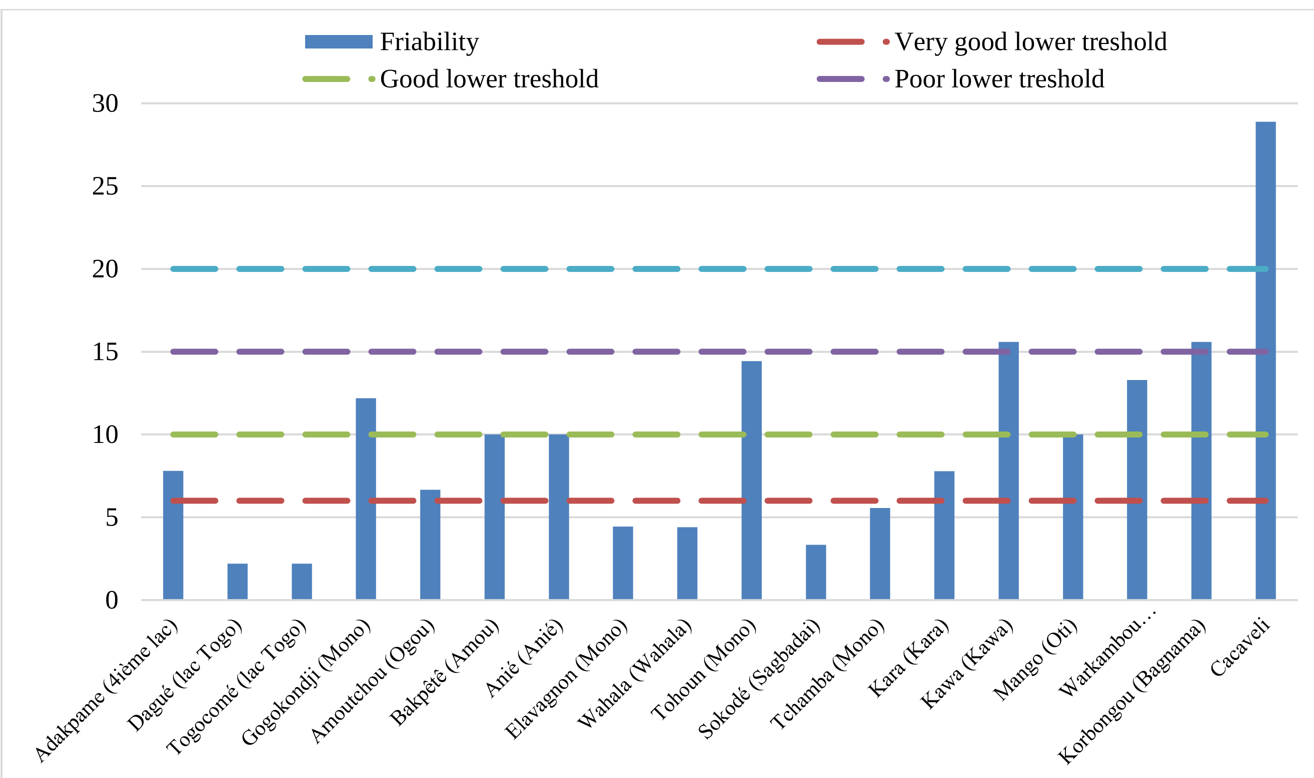

Figure-7: 1500-stroke friabilities of the samples with respect to the normative values.

The analysis of these graphs shows that: i. the bulk density values of the samples meet the standards required for use as filter sand, with slightly low results for the sites of the Sagbadai River in Sokodé and the Mono River in Gogokondji (Tabligbo area). The low bulk density values for these samples can be explained by the nature of the source rock including the density of these minerals, grain shape and granularity. The bulk density values are higher for samples collected in areas other than the "Maritime" region, which may be explained by the presence of outcrops of hard rock in these areas, in the watersheds of the rivers; ii. all absolute density values of the sand studied meet the standards required for use as filter sand. As with bulk density, the highest absolute density values are obtained for samples collected beyond the "Maritime" region. iii. the sands studied have good porosity for use as filter material outside samples from the Kawa and Wahala sites, where the porosity determined is slightly below the lower limit of 40%. A large majority of the river sand samples (88%) have good porosity for use as a rapid filter material. iv. all the samples studied, except those from the Kara and Wahala river sites, have acid solubility values below 2% and are therefore suitable for use as rapid filtration sand, in accordance with European and American standards which set the acid loss limit value at 2%. The acid losses of the Kara and Wahala river sands are nevertheless less than 3, 5%, which is the acceptable threshold in other countries, such as for the Japanese standard[6]. It can be concluded from this that the Togolese river sands generally have a very good aptitude (88%) for acid solubility for use as rapid filtration sand. v. for friability at 750 strokes, the samples from the Korbongou and Kawa sites have slightly poor friability resistance values, those from the Warkambou, Tohoun and Gogokondji sites have good friability resistance and all the rest, i.e. 71% of the samples studied, have very good friability resistance for use as rapid filtration sand. It should be noted that the control material, which is an imported sand taken from the Lomé water treatment plant, has a very low resistance to friability and is absolutely to be rejected as drinking water filtration sand, if we refer to the specifications. For the friability at 1500 strokes, only the sample from the Tohoun site has a poor resistance to friability, those from the Korbongou, Warkambou, Kawa and Gogokondji sites have a good resistance to friability and all the rest, i.e. 71% of the samples studied have a very good resistance to friability, for use as rapid filtration sand. Finally, given that the 1500 stroke test is more rigorous for all materials, it can be concluded from the results that for use as rapid filtration sand, 71% of the river sands studied have very good resistance to friability and 29% show good or poor resistance.

Study of granular characteristics and calibration of the materials: Granular characteristic of the raw sands: From the particle size distribution curves obtained from the sieving of the materials, the effective sizes and uniformity coefficients of the natural materials ($D10_{SN}$ and Cu_{SN}) were determined, the results are presented in the following Figures-8 and 9.

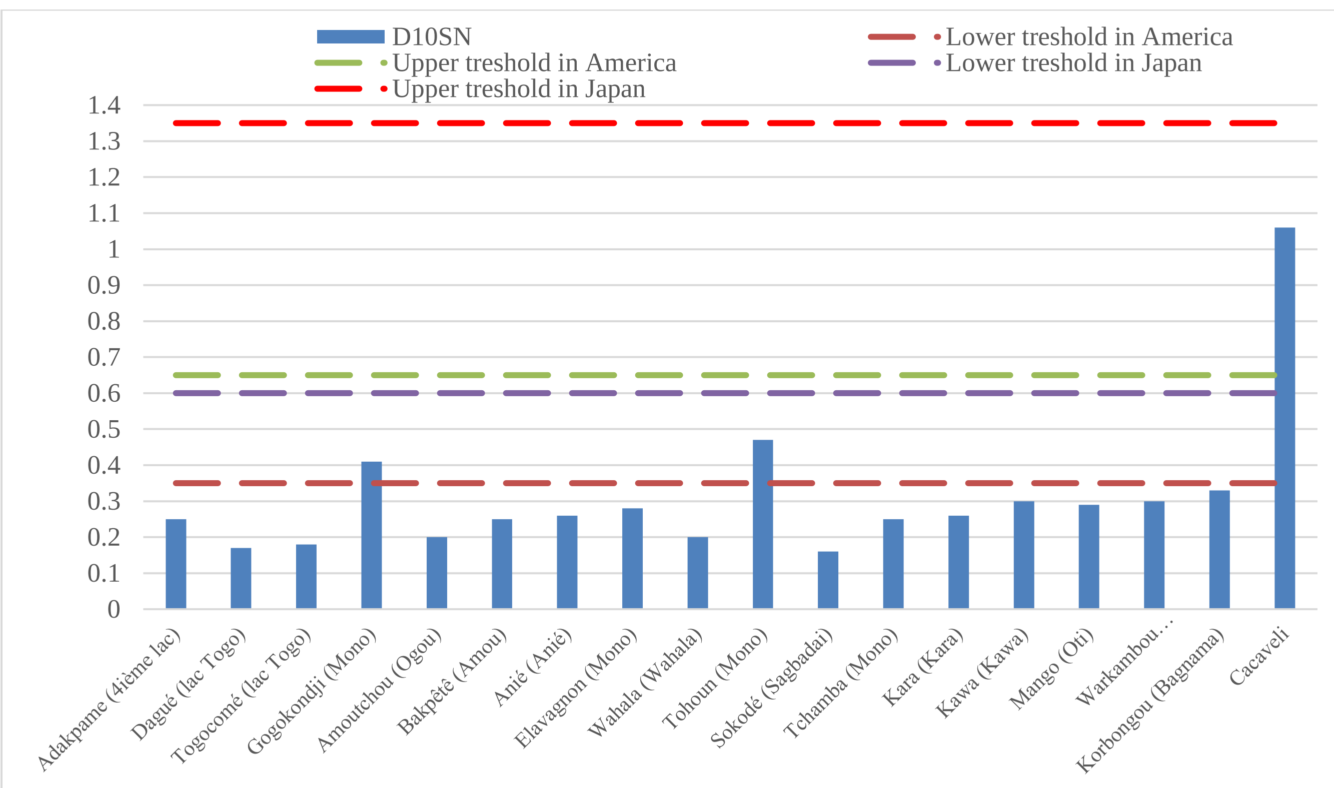

Figure-8: Common effective sizes in rapid water filtration.

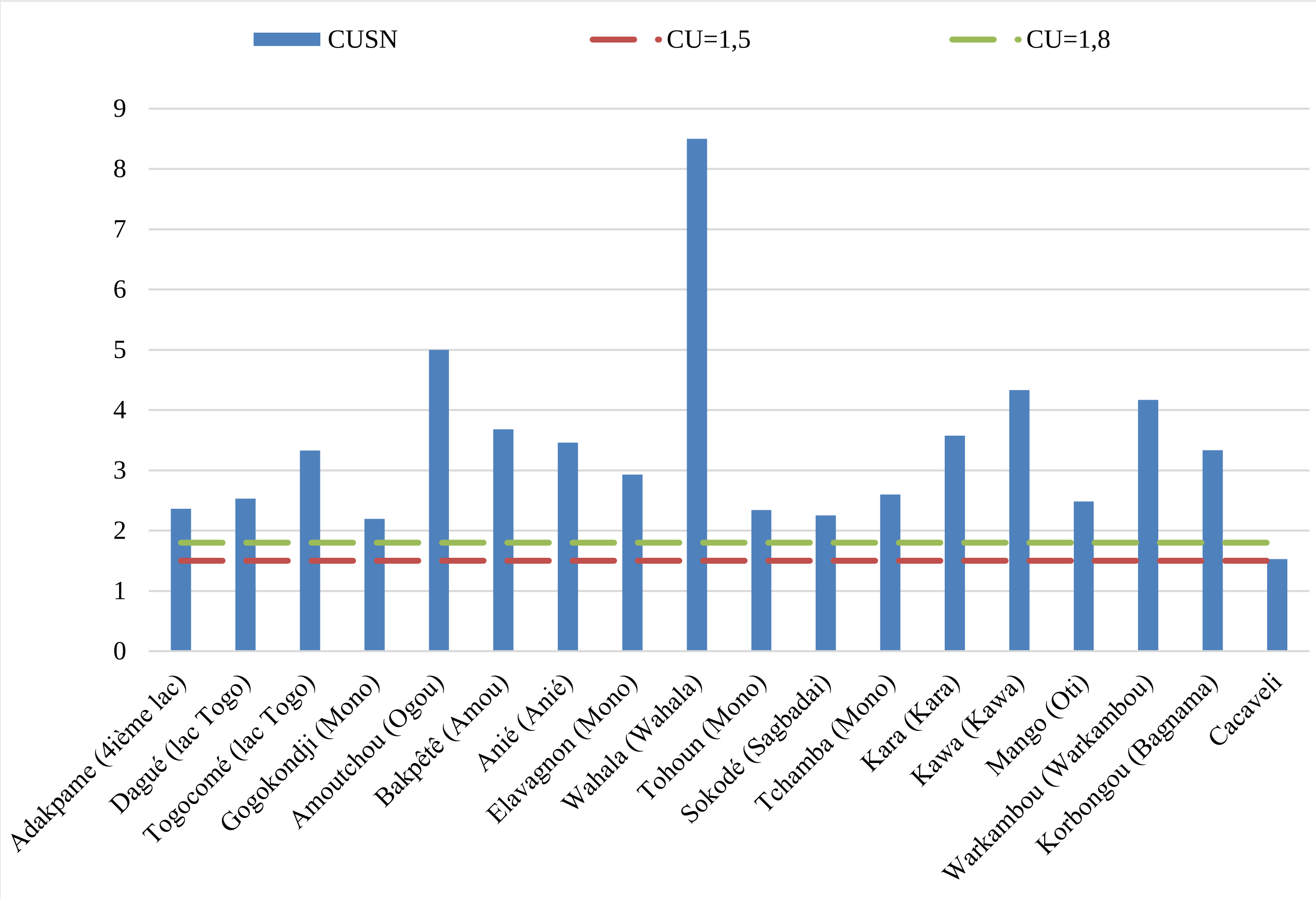

Figure-9: Uniformity coefficients of raw sand compared to normative values.

It emerges from the Figure-8 that the effective sizes of the Togolese rivers sands, in their natural state, are generally very small. 88% of the samples studied have an effective size less than 0.35 mm, which represents the minimum required in America area. With regard to European practices, no Togolese river sand, in its natural state, meets the criterion relating to effective size for use as rapid filtration sand. The graph in figure 9 shows the values of the uniformity coefficients of the sand samples studied compared to the limit values of 1.5 and 1.8. It can be seen that no sample has a uniformity coefficient lower than 1.5 or even 1.8, as required by the standard to have a rapid filtration sand quality. Only the control material from the Cacaveli plant, which is a calibrated sand, shows a Cu value of 1.53, which is acceptable with respect to the upper threshold of 1.8. The use of these sands therefore requires a sizing treatment in order to make the granulometry conform to the desired specification.

Calibration of studied sands according to specifications (C_u = 1,5/D_{10} =1mm and C_u =1,5/D_{10} = 0,6mm): Based on the equations 5, 6, 7, the river sand samples were calibrated against the two above specifications. For a uniformity coefficient of 1,5 and an effective diameter of 1mm, the usable proportions of the materials of the different sites are in Figure-10.

The low usable proportions noted can be explained by the high effective size of the specification (greater than 1mm), whereas nearly 60% of the sands of Togolese rivers can be described as fine. Moreover, the specification on the uniformity coefficient is characteristic of as and with a very tight grain size whereas most of the river sands studied have a spread grain size. Therefore, a relaxation of the specification may allow for an increase in the proportions that can be used as filter sand.

Thus, with the same uniformity coefficient and a smaller effective size of 0,6mm, the usable proportions are greater and are presented, by site, as in Figure-11.

For an industrial production of filters and with a granulometry similar to that specified above, 47% of the samples, with usable proportions equal to or greater than 40%, offer better potential in terms of yield and profitability of the operation.

The treatments to be carried out on the natural sands of these sites will involve the removal of fine and coarse elements. For the effective size of 0.6 mm, the proportion of fine materials to be removed varies, depending on the site, from 18% to 85% and the proportion of coarse materials from 0 to 38%.

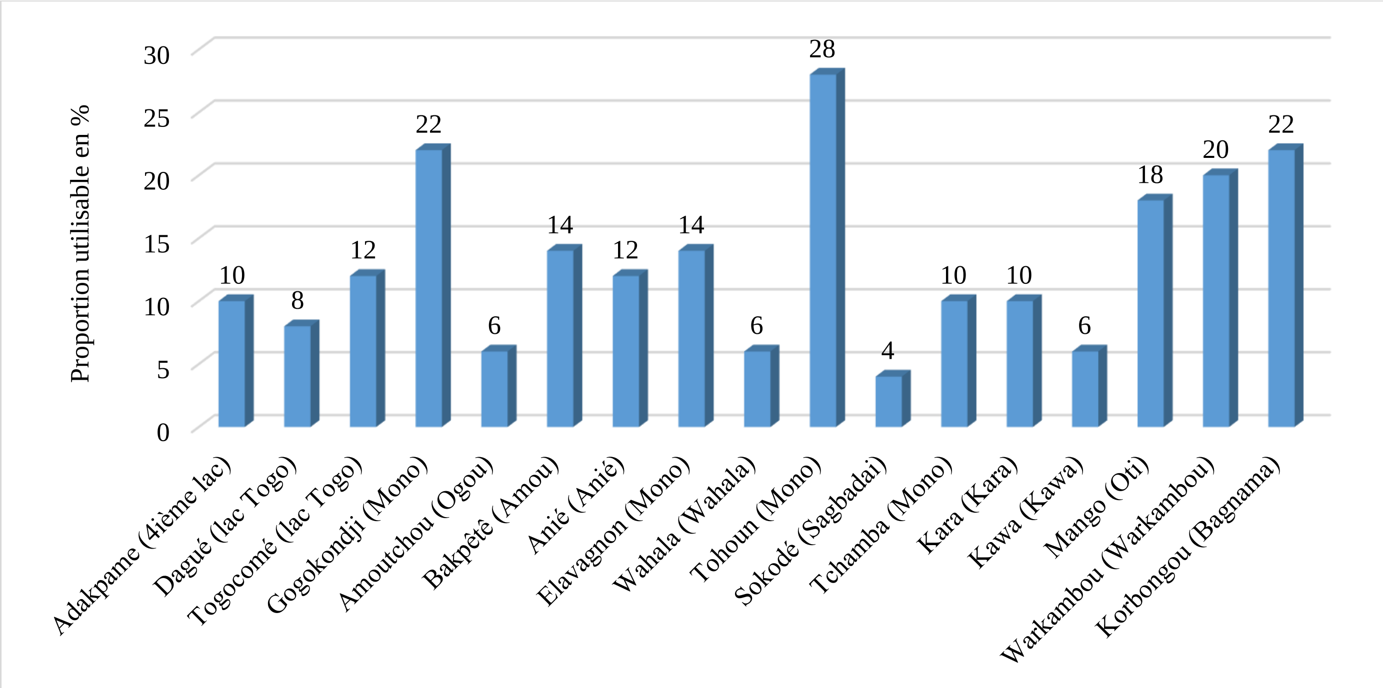

Figure-10: Usable proportions for $C_u = 1{,}5/D_{10} = 1$ mm.

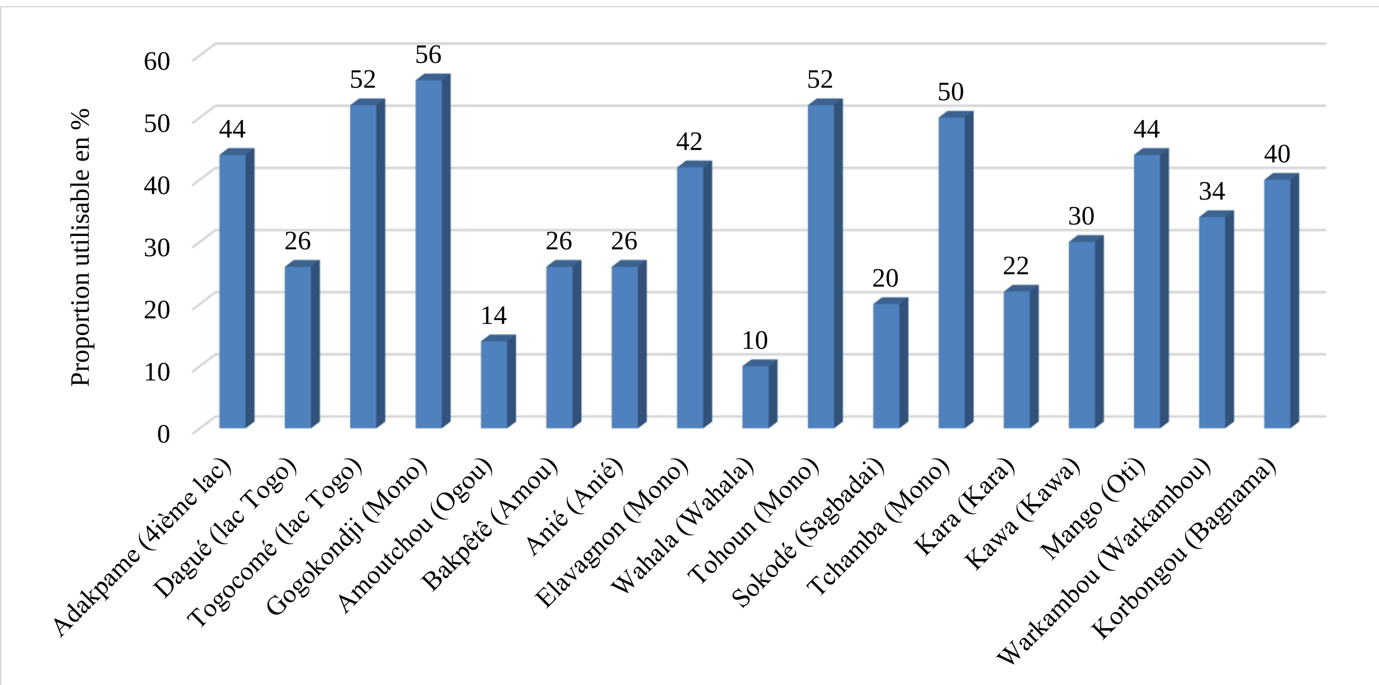

Figure-11: Usable proportions for $C_u = 1{,}5/D_{10} = 0{,}6$ mm.

Conclusion

At the start of this study, the objective is to determine the suitability of river sands, commonly used in Togo in construction, as sand for rapid filtration of drinking water. Following the physical characteristics study of seventeen (17) river sands samples from the five regions of Togo, it emerges that 88% of the river sands studied have a good aptitude for use as a rapid filtration material, with regard to the criterion of bulk density and all the samples have a conform absolute density. A large majority of the river sand samples (88%) have good porosity for use as filter material. 88% of the samples show good acid solubility, 71% have very good resistance to friability and 29% have good or poor resistance. Analysis of the values of the main granulometric parameters (effective size and uniformity coefficient) of the samples reveals that these sands are unsuitable, in their state, for use in rapid filtration. As everywhere else in the world, the use of these sands, whose other normative parameters are globally satisfactory, requires a treatment, by sieving and calibration, to make the granulometry conform to the desired specification. This treatment will thus make it possible to determine, for a given specification of filter sand, the proportion of natural sand that can be used as well as the corresponding granulometric range.

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