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Geometric Drawing Model of Shape of Water Sections for the Investigation of Solid Flow Transport in the Basin of Mono River in Republic of Benin

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Abstract

The hydrologic and hydraulic changings on the behavior of Mono river are the result of the stress involved by human activities, on one hand and the construction of the dam of Nangbéto and the exploitation of sand in downstream of the dam by the population, between Athiémé and Agbanankin on other hand. That effect had also affected the shape of the sections of the river in the context of climate variability. It shows consequently that area is also a trapping area of sediments eroded in downstream of the dam and is responsible for the trapping of sediments in the river. The slope and the flow rate are the main factors of the real capacity of transport of a watercourse. They also determine the transport of solid flows from upstream to downstream. This drawing model established by taking into account the bathymetry of a transversal section of the Mono river at Athiémé, is the first step of a global investigation of the solid flow transport in the basin of Mono river and the boundary condition for the characterization of its hydro-sedimentary dynamics study. It aims to take into account sections and the used technique which consist to measure on one located section as the representative section of the river at Athiémé, by moving the boat used for bathymetry.

Keywords

Mono River, Bathymetry, Geometric Drawing Modelling, Hydro-Sedimentary Dynamics, Trapping

1. Introduction

Mono river is confronted to important damages of erosion due to the floods and the anthropic activities nowadays and had created hydrologic and hydraulic effects on the variation of the behavior of the river [1] [2]. That is responsible for the trapping of sediments around its environment and the eutrophication of the basin [3] [4].

This paper, attends to modelize geometrically the shapes of section of Mono river from Athiémé to Agbanankin and simulate geometrically the section which looks like the average section and thus the more representative section of Mono river, by taking into account the granulometry of sediments and the bathymetry of the river. This bathymetry is necessary for the hydro-sedimentary study of the river, to explain the raising of the basin of the river, the erosion and the flooding in the low valley of Mono river and at least the involvement of the hydro-sedimentary unbalance of the river. The present paper is the first step of the study of a global investigation of the solid flow transport in the river. The first technique consists to measure dimensions (height, length area) on sections with an equidistance of five hundred meters by moving the boat from one bank of the river (point 0) to the second and so on. The technique used is basing on a graduated cord ballasted with 5 kg of lead to stop the waterflow from moving the cord, is submerged for measuring the depth of the river. The measurement had taken place during the dry season. Then we calculated the wet areas from geometric modeling of the shape of the river section.

Before that calculation, the granulometric characteristics of sediments are also determinate, the granulometric curve of the sediments is drawn and finally the geometric model of the sections is simulated and has been drawn.

The variation of the profile of the shapes of section of Mono river depends on the granulometry of the sediments and the erosion of the banks of the river [5].

2. Presentation of the Study Area

The watershed of Mono River is shared between Benin and Togo. The high and average parts of the basin are largely in Togolese territory. The Mono River has its source in the north-west of Benin in the mounts Koura, region of Bassila. Its length is 530 km, and used as a natural border between Togo and Benin on almost of 148 km. Its watershed covers an area of about 25,000 km^2 between the latitudes 6˚10' et 9˚00' North and longitudes 0˚30' et 1˚50' East of relief little contorted, it is made up of coastal plains, plateau, lagoons and shallows. The downstream part, subject of the present study is an area located between the border Togo-Benin and the outlet of river, that to say a portion of about 148 km^2 of area (see **Figure 1**) [6].

The basin of the Mono river, presents from the north to the south, three climate areas with more or less distinct demarcations like said on the **Figure 2**. It is about:

- The first area marked by the rain which start at the end of April, and increases linearly to peak on august before initiating a steady decline to stop by mid-November. In this area, the rainiest months are July, August and September;

the rainfall totals can reach 1380 mm and the dry season is from mid-November at the end of April. The average temperature is in order of 27.0˚C;

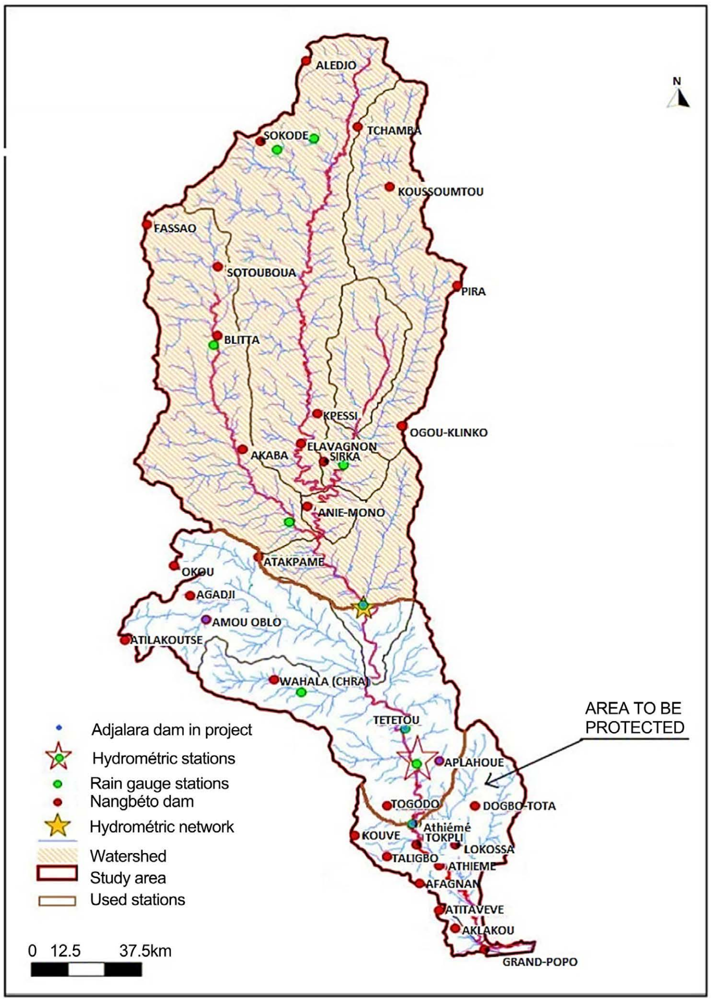

Figure 1. Location of the study area; (Azonsi F. *et al.*, 2010).

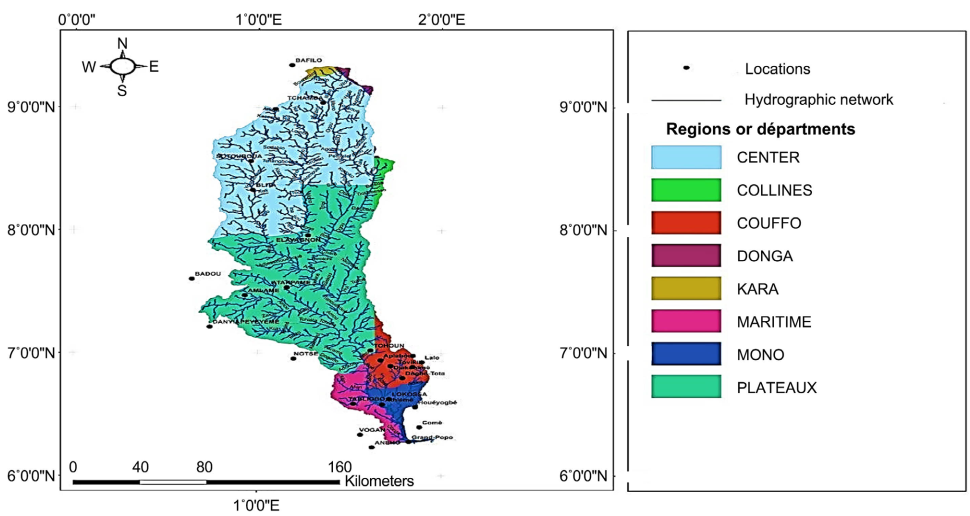

Figure 2. The climate zones of the basin of Mono (SAWES, 2010).

- A second area which is under strong orographic influence, and therefore very rainy. In this second area, the rainfall totals exceed very often 1500 mm. It rains continuously between April and mid-November with a slight increase in precipitation during months of June and July;
- A third area with two rainfall peaks, the most important of which is at the month of June and the least important is at the month of September. The average of the annual rainfall totals exceed largely 1000 mm. in this third area, we note a climate anomaly marked by a relatively dry climate with an average annual rainfall oscillating between 800 and 850 mm, with the rainfall peaks which are registered in June and October [6].

The relative humidity in the lower valley is extremely high and varies between 65% and 95%. It varies very little in the journey (89% at 6 h UT, 73% at 12 h UT and 81% at 18 h UT). Those winds, with prevailing direction south-west and north-east, have an average velocity of 4 m/s at Nangbéto and can reach 15 to 20 m/s during a storm in the lower valley.

The data used in this study (hydrologic, hydraulic, topographic, bathymetric, geologic and geographic) are collected directly from Executive Management for Water (DG Eau) and Benin Electric Community (CEB). The synthetic source of used data are shown in **Table 1**.

2.1. Rainfall in the Watershed

The flow in the basin of Mono is very variable. The north of Togo is subject to a tropical transition climate characterized by dry season from October-November to March-April and a wet season from March-April to October-November. The south region of Togo is subject to an equatorial climate characterized by a dry season from mid-November to March and a wet season from March to mid-November, interrupted by a small dry season in August and September. The floods of Mono begin therefore generally in March and extend on five or six months in average. **Figure 3(a)** highlights the classes of seasons in the basin of Mono, divided into three types of domain (subequatorial domain and humid tropical domain) according to the latitude and thus **Figure 3(b)** shows the rainfall variability class by class from january to december in the basin of Mono (**Figure 3**).

The most important rainfalls on the basin, are registered from April to October. During this period, the precipitations are unevenly distributed on the basin; the south of the basin is very watered in June, comparatively to the north which is wet with the most abundant rains from July to September. That could be explained by the cumulated effect of monsoon and the relief. So, the rainfall started earlier in the south than in the north of the basin. The **Figure 4** shows the longitudinal profile of the river [6].

According to Le Barbe *et al.* (1993), in average year, the annual average flow of the Mono River is in order of 100 m^3/s at the station of Athiémé; but since 1988, with the production of electric power, the hydrological regime of Mono had been modified with the low water period sustained by an average flow rate of 40 m^3/s [3].

Table 1. Rainfall measurements at different hydrometric stations.

Data	*Sources*	*Region/station*	*Period*	*Geographic situations*		
				Latitude	*Longitude*	*Altitude* (*m*)
Flo flow rates	DG Eau Cotonou	Athiémé river	1968-2008	06˚34'44"N	01˚39'53"E	8.2
	CEB	Dam Nangbéto down river	1987-2008	07˚25'N	01˚26'E	150

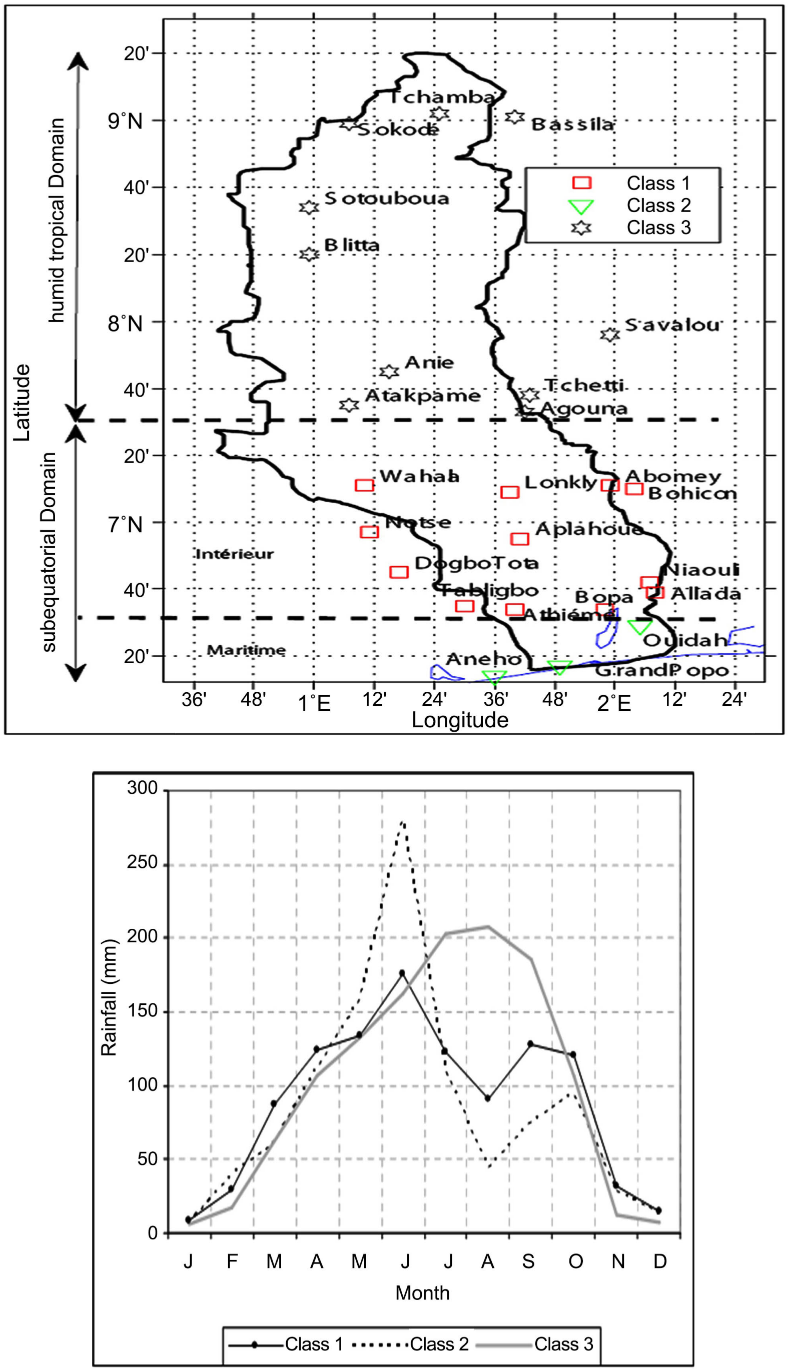

Figure 3. Rainfall variability in the basin of Mono (AMOUSSOU, 2019).

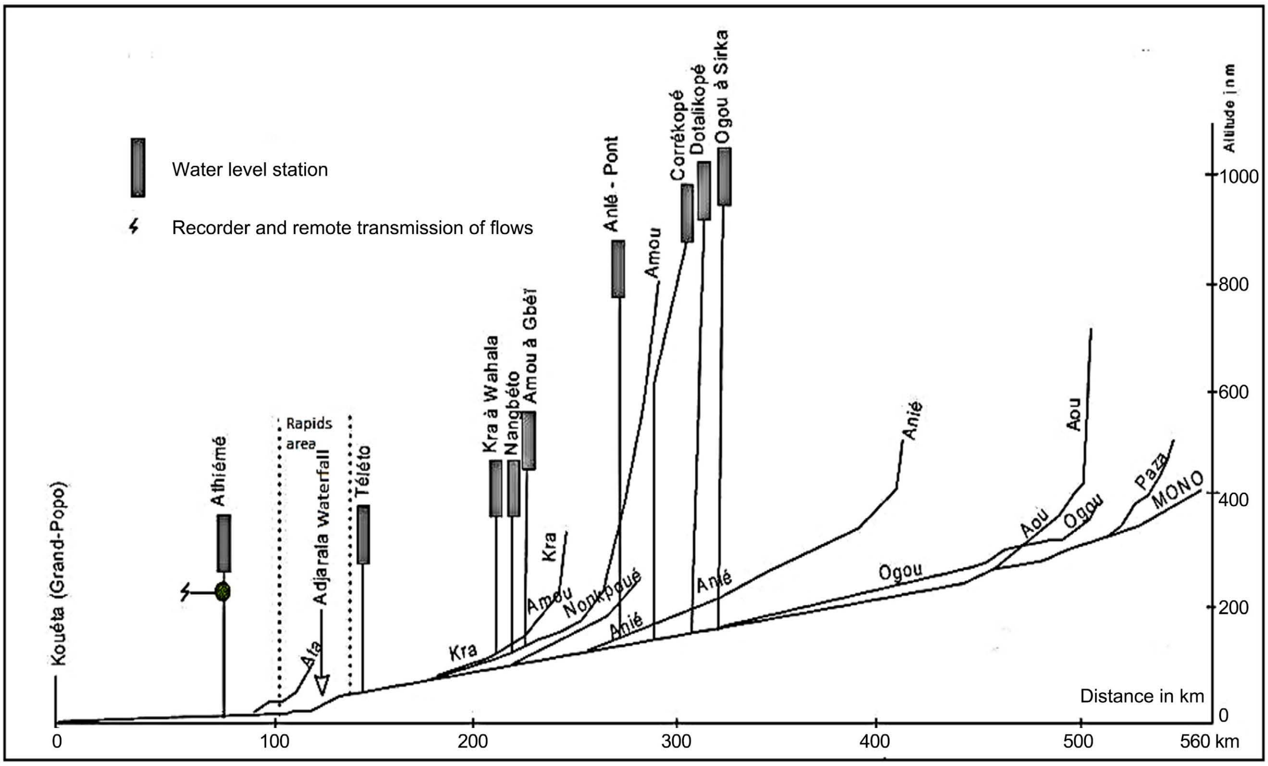

Figure 4. Longitudinal profile of Mono river and its affluents (Le Barbe *et al.*, 1993).

2.2. The Outflow in the River of Mono

The problem of outflow in the river can be summarized as follows: there is on one side the gravity which tends to flow the water and on other side the bed friction (bed and bank) which tends to slow down the flow. The influence of the gravity on the flow depends on the slope, while that of the friction depends on the flow characteristics and the solid interface characteristics (granulometry and topography). For certain flow rates, the flow conditions depend therefore on the slope and also on the fluid flow rate and granulometric and topographical properties of the bed. When the flow velocity is such that the variations of water height induced by topographical perturbations, it cannot move upstream; it is the case of torrential flow. This case is only found in mountain torrents or in special cases (outlet of the limon); otherwise the flow is supposed to be fluvial. It exists between those two cases, a very marked difference in behavior. The cases encountered will be always in fluvial regime. Concerning the applying friction, only on the solid banks of flow (bed and bank), the flow velocity is not uniform in the section. In rectilinear section, the maximum value of velocities of the area is located at the middle of the section, and near the free surface, and therefore, the regime of flow in the river is generally highly turbulent. Turbulent flow features will therefore arise with origin, all areas where strong gradient of velocities are generated; *i.e.* bed and banks and also all topographic discontinuities of the bed. The maximum size of those turbulent flow features is limited by the maximum spatial scales according to the considered direction (height of water in the vertical plan and width of transversal section in the horizontal plan). Those flow features play an important role in the deformation of bed by the outflow.

3. Materials and Methods

3.1. The Particles Size of Sediments

Different parameters defined from the particles size distribution can be used to characterize the mixture. Many characteristic diameters of the mixture can be defined, as the median diameter D_{50} or the average diameter. The explanation of the effects of mixture is the following; the big grains in a mixture are more exposed to the flow than if they were the only ones represented in the bed, and conversely for fine grains. In consequence, the big grains are easier to move and their transport will be more increased than if they were the only ones, conversely for the small grains. This phenomenon is known as "masking et exposure". This effect tends to counteract the difference of intrinsic mobility of grains. We can imagine that all of grains of the mixture are mobile in same time regardless of their size: so there is no selective transport. This case is not general (it can be considered as approximation, and only in certain cases). One consequence of the transport preferential of finer sediments is that the granulometry of transported sediments is usually finer than that of sediments of the bed [7].

One general characteristic of rivers is that the sediments which compose the bed are increasingly fine in downstream direction. This phenomenon provoked by the preferential transport of most of fine sediments as well as by abrasion, and is associated to a decrease of the slope of the bed to downstream. The diameters of the grains of bed can go of many tens of centimeters in the torrents of mount, to some tens of millimeters at the outlet of the rivers [7].

3.2. The Sediments Sampling Granulometry

The sampling is carried out in three ways: by the Bertois's cone, by coring and diving. With the Berthois cone, we operate on a canoe or a motorized boat, during coring on the banks and finally with the divers. The realized sample have been analyzed in the laboratory CGILE in Togo and in the laboratory of Sciences of Earth Department of University of Abomey-Calavi, Benin [5]. The experience is realized according to the AFNOR series (French Association of Normalization). The screen column is constituted by 5 sieves with decreasing geometrical dimensions of meshes allowing to distinguish soil materials ie. gravels (>2 mm), very coarse sands (>1 mm), coarse sands (>0.5 mm), medium sand (>0.2 mm) et fine and very fine sand (>0.05 mm). The **Figure 5** presents the granulometric curve of sediments in Mono river.

From the particle size distribution curve of sediments of the bed bottom [8], we got $D_m = 0.75$ mm and $D_{50} = 0.375$ and the uniformity coefficient can be calculated with the following formula:

$$Cu = \frac{D_{50}}{D_{10}} \tag{1}$$

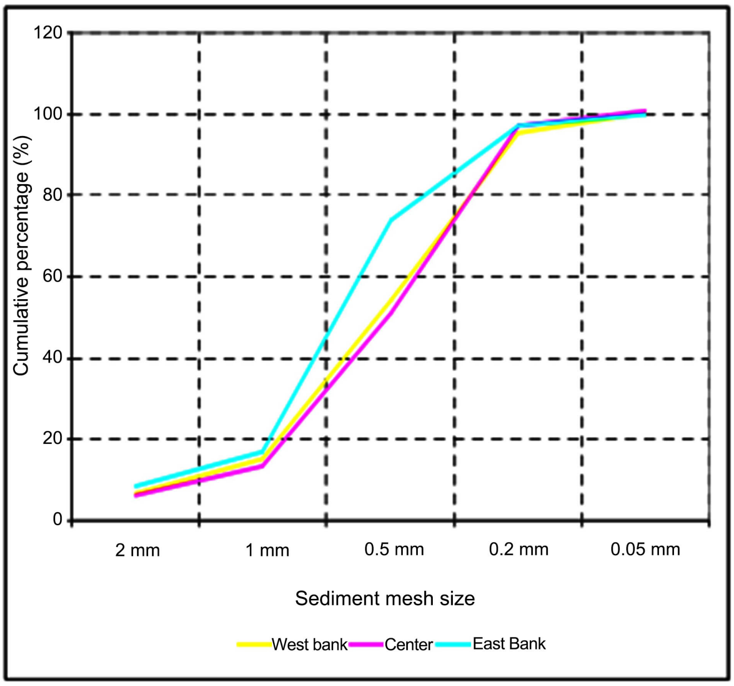

Figure 5. Particles size distribution curves of sediments of the Mono river (Codo, 2019).

After the granulometric analysis, the results obtained for the different sands are as follows:

For clays and other sediments derived from clays, diameters are between 0.002 mm and 0.05 mm; for fine sands, the diameters are between 0.05 mm and 2 mm; from medium sand to rough sand, grains diameters are higher than 2 mm [8].

The uniformity coefficient (Cu) of grains indicates the type of granularity of grains. In the case of $Cu < 3$, the granularity is uniform. Thus consequently, in the case of Mono river, $Cu = 0.33$, ($Cu < 3$), thus the particle size distribution is uniform. Through the granulometric curve, different diameters are determinate (**Figure 6**).

Table 2 shows the different values of calculated diameters.

The coefficient of Strickler β, is essential for the determination of wet perimeters in the Mono river.

So

$$\beta = \left(K_f / K_g\right)^{3/2} \tag{2}$$

where

K_f: roughness of the bottom

K_g: Roughness of grains

$$K_g = 21 \big/ \left(D_{50}\right)^{1/6} \tag{3}$$

Table 3 shows the different values of K_f, K_g and β [8] [9].

The wet perimeter can be calculated with the following expression [10] [11]:

$$P_m / K^{3/2} = P_f / K_f^{3/2} + P_b / K_b^{3/2} \tag{4}$$

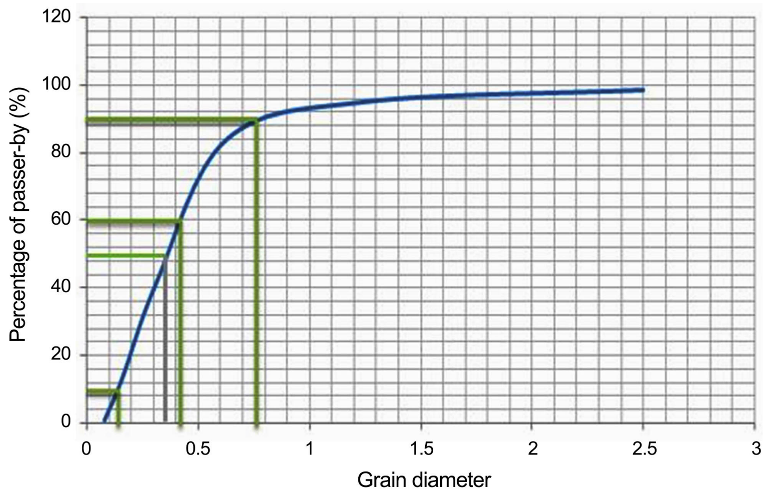

Figure 6. Determination of different diameters in the granulometric curve (Codo, 2019).

Table 2. Calculation of the values of different diameters.

Diameters	D_{10}	D_{50}	D_{60}	D_{90}	D^*
Values	0.14	0.375	0.48	0.78	9.4828

Table 3. Different values of the coefficients: K_f, K_g and β.

Coefficients	K_f	K_g	β
Values	20	24.73	0.73

where

P_m: wet perimeter

P_f: width to top

P_b: length of bank and the different values used are: $P_{b1} = 6.33$ m, $P_{b2} = 29.53$ m

3.3. Bathymetric Sampling Techniques

The bathymetric sampling techniques include depth and sediment samples. This bathymetric measurements are operated on 10 km with an equidistance of 500 m, so we got 20 measuring stations. The measurements of bed of watercourses have been realized in dry season (low water period) between Athiémé and Agbanankin, thanks to two artisanal techniques which take into account the section to be measured.

The first technique consists to measure on sections with an equidistance of five hundred meters by moving the boat from one bank of the river (point 0) to the second and so on. The graduated cord ballasted with 5 kg of lead to stop the waterflow from moving the cord, is submerged for measuring the depth of the lagoon (**Figure 7**). Each depth measurement is accompanied by the taking of coordinates at the measurement point of the starting river bank at the arrival river bank. The determination of the depth being difficult, especially in time of frequent violent wind (5 m/s or even 10 m/s on a watercourse of 2.5 at 3 km wide), the rating technique consists to quantify two orders of magnitude which are the width and the height of water in one point. The lead comprises a cavity at its end making it possible at the same time to take sample of sediment [3] [4].

The second technique consists to extend a graduated rope with the use of a pirogue, supported on both sides by stakes. This technique concerns the gauging of the bed and the bathymetry to low water period (**Figure 8**) [5].

4. Results and Discussion

4.1. The Shape Geometrical Model of the River at Athiémé

Up to now, data of Mono river remained incomplete. Thanks to bathymetry and to the calibrated measurement of depth and of the survey on a number of sites, the transversal profile of the river (down-Mono), is reconstituted, to identify the evolution of the filling, comparing to the previous works. The movement of sediments, which shapes the bottom of the river, is a complex phenomenon. To study the geometry of this watercourse, we assimilated the bathymetric curve of the river to a regular form of figure. So, the following figure present on one hand, the measured bathymetry of a section of the upstream at the station of Athiémé (**Figure 9**) and on other hand, we present the simulated transversal section of the river at Athiémé (**Figure 10**).

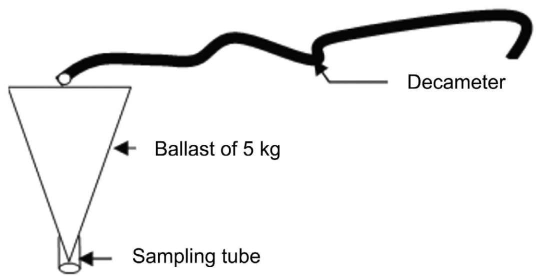

Figure 7. The thread weighted technique for bathymetry (Amoussou, 2005).

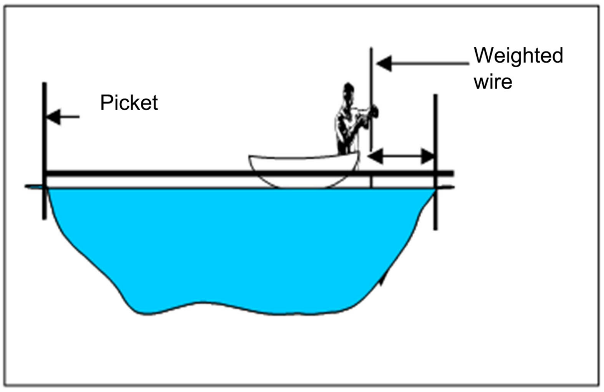

Figure 8. Technique of graduated rope with use of pirogue for bathymetry (Amoussou, 2005).

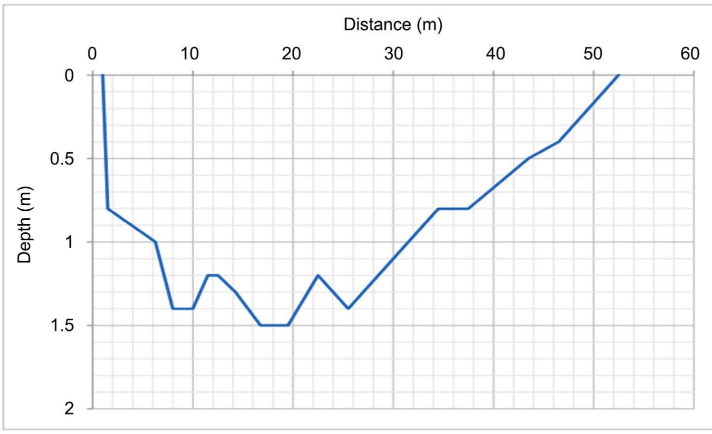

Figure 9. Bathymetry of the section of the river upstream at the station of Athiémé.

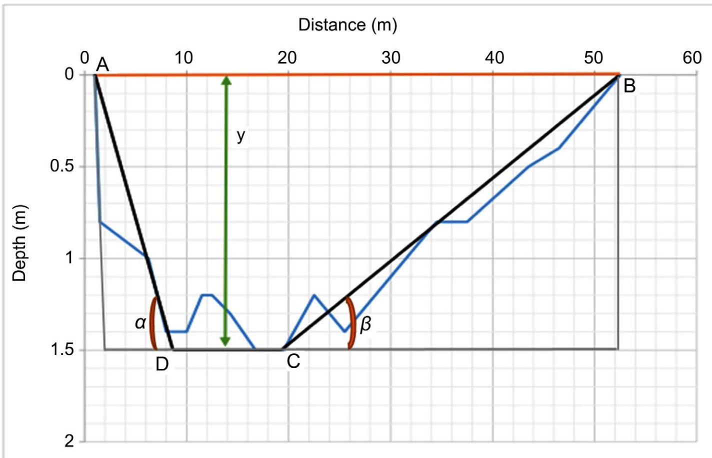

Figure 10. Simulated section of the upstream river at the station of Athiémé.

All section of the Mono river at Athiémé, may be calculated according to the simulated form, where

Y: the water draught

AB: the width of glassy water

DC: the width on top

AD: the left of bank

BC: the right of bank

Considering S_k as the area of the river section located at K point on the average line of longitudinal profile [12], we have:

$$S_k = \begin{cases} 0 \quad \text{if } x_i - x_0 = L_k \\ y \quad \text{if } x_i - x_{i-t} = l_k \\ z_k = k\dfrac{W}{n} \end{cases} \tag{5}$$

where $0 \le k < L_b$, $0 \le i < L_k$, $0 \le j < y$ and $0 \le t < i$.

$$L_k = \sqrt{\left(X_j - X_i\right)^2 + \left(Y_j - Y_i\right)^2} \quad \text{and} \tag{6}$$

$$l_k = L_k - y\left(\frac{1}{\text{tg}(\alpha)} + \frac{1}{\text{tg}(\beta)}\right) \tag{7}$$

L_k is the width of glassywater, l_k the width on the top, z_k position of the section on the average line, n the step in the space and L_b the length of the reach. X_j, X_i, Y_j et Y_i are the topographic coordinates of the bank [12].

4.2. Evaluation of the Geometric Parameters

The study of different geometric parameters of the river on the reach is based on the analysis of the bathymetry in twenty (20) measuring sections of the river from Athiémé to Agbanankin. Considering the sinusoidal character of the river, its geomorphology is handmade by the hydraulic turbulences of meanders. With the geometric model, we evaluate the width to glassy water and to top of the river in the reach on 10 km with a step of 500 m. The knowledge of dimensions of the sections of the river allowed to evaluate the dimensionless stress (Shields parameter) in order to determine the transport mode of grains. Table 4 recaps the dimensions of the sections to each point.

Figure 11 shows the longitudinal profile of the river (left bank and right bank) in the reach upstream of the station of Athiémé, showing four (4) meanders on just 10 km. The river is therefore very sinuous; and its sinuosity had highly influenced the dynamic of watercourse.

Table 4. Evaluation of the dimensions of the cross sections of the river from Athiémé to Agbanankin.

Positions of sections (z_k)	Width to Glassy water (A_k)	Width to top (B_k)
00	47	7
01	68	28
02	86	46
03	76	36
04	98	58
05	106	66
06	116	76
07	79	39
08	45	5
09	55	15
10	53	13
11	60	20
12	46	6
13	51	11
14	66	26
15	73	33
16	56	16
17	45	5
18	84	44
19	51	11

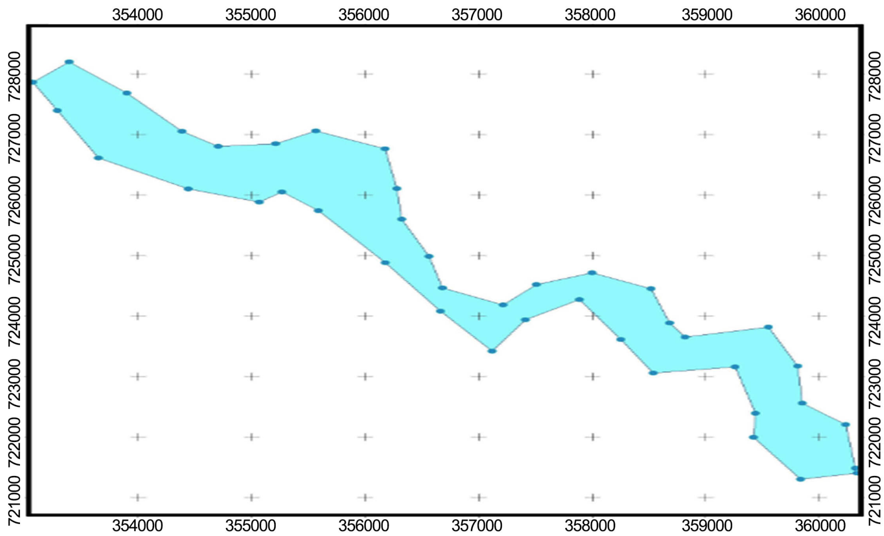

Figure 11. Plan view of the banks in UTM coordinates upstream of the station of Athiémé.

5. Conclusion

The geometric drawing model of the shape of sections of Mono river shows the form of the section of the river at Athiémé. The granulometric characteristics of sediments are determinate and the granulometric curve is drawn. At least, the geometric model of the sections is simulated and had been drawn. The second step of the study will be to analyze the behavior of the river through the variation of the profile of sections which depends of the drawn geometric model, the presence of strong sediments in the river and the erosion of the river banks. After the analysis of the curve, the movement threshold of the grains is not reached ($\tau^* > 0.047$) in over one section calculated by the geometrical model. This includes that the big part of materials which are deposited in the bed of the river comes from the erosion of banks and basin.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Anthony, E.J. and Blivi, A.B. (1999) Morpho-sedimentary Evolution of a Delta-Sourced, Drift-Aligned and Barrier-Lagoon Complex, Western Bight of Benin. *Marine Geology*, **158**, 161-176. https://doi.org/10.1016/S0025-3227(98)00170-4

[2] Amoussou, E. (2010) Variabilité pluviométrique et dynamique hydro-sédimentaire du bassin versant du complexe fluvio-lagunaire Mono-Ahémé-Couffo. 315 p. https://hal.archives-ouvertes.fr/tel-00493898/

[3] Amoussou, E. (2005) Variabilité hydro-climatique et dynamique des états de surface dans le bassin versant du Couffo. Mémoire de DEA, FLASH/UAC, 105 p.

[4] Blivi, A.B. (1993) Géomorphologie et dynamique actuelle du littoral du golfe du Bénin, Afrique de l'Ouest. Thèse de Doctorat, Université de Bordeaux 3, 458 p.

[5] Blivi, A.B. (2000) Effet du barrage de Nangbéto sur l'évolution du trait de côte: Une analyse prévisionnelle sédimentologique. *Journal de la Recherche Scientifique de l'Université de Lomé*, **4**, 29-41. https://doi.org/10.4314/jrsul.v4i1.16996

[6] Gangbe, C.F. (1988) Etude et cartographie et l'environnement de l'estuaire du fleuve Mono. Université Nationale du Bénin.

[7] Codo, F. de P. and Senou, L. (2017) Calculation of Wet Areas from the Geometric Modeling of the Shapes of Sections of the Lagoon of Cotonou, Benin. IJSER, 2017, 1497-1502.

[8] Codo, F. de P. and Senou, L. (2017) Characterization of the Hydrosedimentary Dynamics of the Estuary of Ouémé River in Cotonou, Benin. IJSER, 2017, 130-138.

[9] Einstein, H.A. (1950) The Bedload Functions for Sediments Transport in Open-Channel Flows. Technical Bulletin N°1026, U.S. Department of Agriculture, Soil Conservation Service, 71 p.

[10] Engelund, F. and Hansen, E. (1967) A Monograph on Sediment Transport in Alluvial Streams. Teknish Forlag, Copenhagen, 62 p.

[11] Kondolf, G.M., Montgomery, D.R., Piégayet, H. and Schmitt, L. (2003) Geomorphic Classification of Rivers and Streams. Tools in Fluvial Geomorphology. G. M. Kondolfand H. Piégay Chichester, John Wiley and Sons, 503-537.

[12] Parker, G. (2007) Transport of Gravel and Sediment Mixtures. Draft of Chapter 3 for ASCE "Sedimentation Engineering".
http://cee.uiuc.edu/people/parkerg/manual_54.html
https://doi.org/10.1061/9780784408148.ch03