Calculation of wet areas from the geometric modelling of the shape of sections of the lagoon of Cotonou,Benin

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Abstract— The main causes of the hydrologic and hydraulic changements which are taking place in the lagoon of Cotonou, are the construction of the seaport and the construction of the dam of Cotonou. They are the principal responsible for the trapping of the discharged sediments in the lagoon of Cotonou by the nokoué lake.
This paper presents the first step and the boundary condition for the characterization of the hydrosedimentary dynamics study of the estuary of Cotonou. It aims to take into account the tranversal sections of the lagoon of Cotonou, small channel of the Ouémé River. The technique used consists to measure on big sections with an equidistance of three meters by moving the boat used for bathymetry from the first bank of the river (point 0) to the second one, and so on .The graduated cord ballasted with 5kg of lead to stop the waterflow from moving the cord, is submerged for measuring the depth of the lagoon. The measurement had taken place during the dry season. Then we calculate the wet areas from the geometric modelling of the shape of sections of the lagoon. This calculation which takes in account the bathymetry of the lagoon, is useful for a better appreciation of the evaluation of the evolution of the geometry of the sections of the lagoon and the evoluation of the sedimentary dynamics of sediments in the river.

Index Terms— bathymetry, dam, estuary, hydro-sedimentary dynamics, modeling, trapping.

Nomenclature:

R_h : hydraulic radius
s : wet area of section
u^* : Friction Velocity
L_k: width of glassywater
l_k: width on top
y_k;:draught
Y : water draught
AB : width to Glassywater
DC : width on top
AD : left bank
BC : right bank

1 INTRODUCTION

This paper is initiated to modelize geometrically the shape of sections of the lagoon of Cotonou, estuary of the Ouémé River, taking into account its bathymetry, and to calculate wet areas from the geometric models of the shape of sections of the lagoon. This is necessary for the hydro-sedimentary dynamics study of this estuary,to explainthe consequences of the effect of climate change on this estuary. In Benin, the lagoon of Cotonou is a small channel, 5 km long, 300m wide and 5m to 10m deep, where continental waters are in contact with the oceanic salt waters. It was built in 1885, to access to the Atlantic Ocean and to be the outlet for annual floods of Lake Nokoué. Since its opening, it is the place where estuary dynamics is taking place. It occupied a big part of the so-called the dynamic lagoon complex of Nokoué River and Porto-Novo lagoon with three bridges and one dam.
Since the construction of that dam, the estuary bottom geometrical dimensions models varies because of the opening of the channel on Atlantic ocean, and then partial studwork (filling) of the channel was registered. Nowadays, that created environmental problems as example, the continental erosion on the site. The interest of this study is to appreciate theoretically the variation of the shape of sections of the lagoon in function of the bathymetry of the

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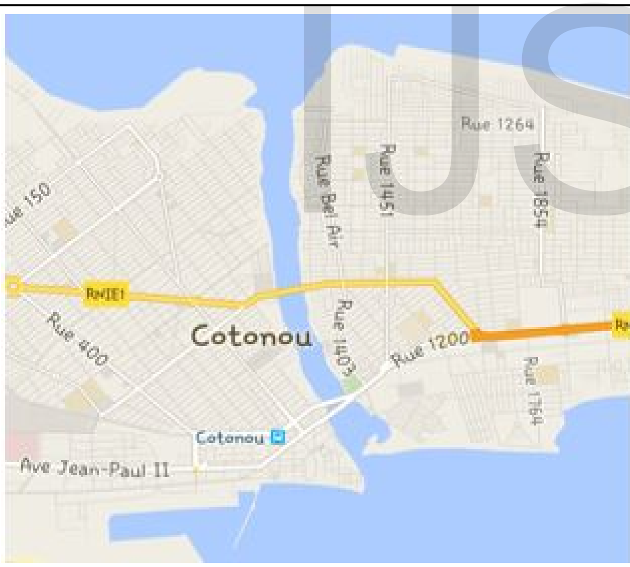
channel and its evolution.

2 Presentation of the Site

The lagoon of Cotonou is the channel through which the inland waters are in contact with the sea water. This channel was excavated in 1855 and then, in order to connect the Atlantic Ocean to the lake Nokoue to serve as an outlet for annual floods of the lake. Several works of civil engineering have been built on the lagoon of Cotonou. Length of 4.5 km and width of 300 m, this channel reaches funds of 5 to 10 m along the western shore [1] and constitutes the seat of the estuary dynamic (small estuary of Lake Nokoué).

Since its realization in 1855, the pattern of the bottom has varied a lot because of, one part, the continuous opening of channel on the Atlantic Ocean which resulted from an increase of the depths and on other part, of the construction, in 1979, of the dam located to 250 m of an outlet which fosters partial filling of the eastern half of the channel. At certain times of the years, the relations between the lagoon of Cotonou and the sea are totally cut off by the formation of the sandy arrow.



Map 1: Channel Sharing Cotonou in two parts (Google Map)

2.1 Dynamic of Lagoon of Cotonou before 1963

Before 1885, Cotonou was subject to large floods that coincided with the flood of the lake Nokoue. To solve this problem, they duged the 21 September 1885 a trench, which is 1.5 m wide and 1 m deep to join the lake Nokoué to the sea. In a few hours, by the current strength that suffered, this trench has reached 200 m wide and 500m a few days late [8]. The freshwater expanse which was the channel has come into contact with the sea. From this moment, we noted the periodic openings and closures at the outlet of channel, remotely guided by the littoral drift and the extent of the flood (opening during the flood period and closure during low-water period). When the flood of the lake Nokoue wasn't strong enough to open the channel, they were evacuated by the channel of Totchè as was done before the opening of channel.

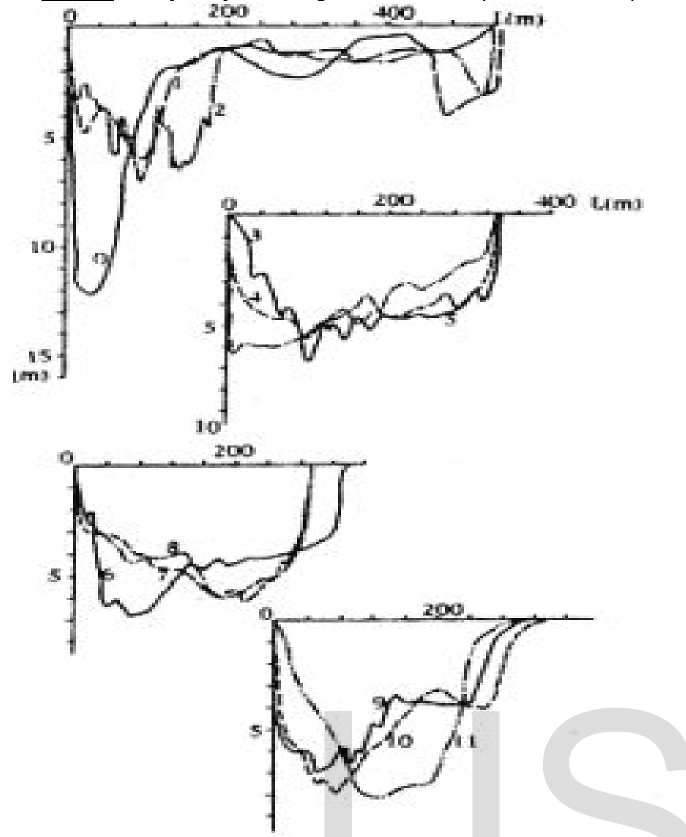
Before the building of port of Cotonou, the littoral drift closed the channel after allowing an important saltwater intrusion. This intrusion resulted from the increase of salinity (up to 38% of salinity) in the channel of Cotonou during a low-water period.

2.2 Dynamic of Lagoon of Cotonou between 1963 and 1977

From 1963, the channel of Cotonou has been constantly opened because of the building of port of Cotonou. The main work responsible for this change is west pier of the port. This work prevents the formation of the littoral drift and causes the deposition of sand of west side thus depriving the coastal current of its sand. The coastal current, deprived to their sand are became more erosive, picking up the sand in the west side and thus causing a permanent opening of the channel. This permanent opening of channel has allowed to the saline intrusion to reach the lake Nokoue and the lagoon of Porto-Novo through the channel of Totchè and has also greatly facilitated sea-lagoon trade end the sediments exportation [9]. One of the consequences of the sediments exportation is the scraping and scouring pillars of the old bridge of Akpakpa.

One other consequence of the permanent opening of the channel is a radical modification of the salinity of the lake Nokoue and the lagoon of Porto-Novo. Theirs salinity rates range from 0 à 30 g/l [10]. This important saline intrusion had the effect of deterioration of the fishing with a drop in production of 10090 tones approximately between 1959 and 1975 for the lagoon complex lake Nokoue-lagoon of Porto-Novo. The following curves show the curves of bathymetry of the lagoon of cotonou in 1993 [4].

Annexe: Bathymetry of the lagoon of Cotonou (A. B. Blivi 1993)



2.3 Dynamic of Lagoon of Cotonou from 1977 to today

To solve the many problems linked to the construction of port of Cotonou, the government of Benin has decided to build in 1977 a dam to outlet of channel. The building of dam had for main objectives:

-to limit the sea-lagoon trade thanks to the reduction of the exchange section

-to avoid the flood in the Cotonou City

-to protect the bridges by reducing of the current velocity

-to slow the rate of decline in order to extend the reproduction periods and the growth periods of the freshwater species.

The dam of Cotonou is composed of a dike of 420m approximately and of 6 narrows 6m wide. It has a mechanism of setting sea-water. During the building of the dam, the shoreline was increased by 0, 32 m in relation to the outcome of the feasibility study. Before the end of the building of the dam, the lagoon current have suffered a significate reduction, which resulted the formation of the sandy shoal behind the dam. This sandy shoal has taken gradually of the height and caused a gradually and total closure of the channel the 6 may 1978 with the biologic consequences more catastrophic than in previous stages.

This closure of the lagoon of Cotonou has resulted in floods during the flood periods intersected by several low-water period in 1978 and 1979 [11]. The crest of the dam has been built on the coast IGN of 0,9m instead of 0.4 m as recorder in the feasibility study. In august 1979, we have artificially opened the channel of Cotonou and left the narrows opened in permanence. The salinity of the low-water period has never again reached the pre-construction maximum values of the dam. This decrease is due to the fact that the armourstone is an obstacle for the saline intrusion and promote the evacuation of one part of floods by the channel of Totchè. The current velocities have therefore decreased considerably in the channel, which caused an increase of the speeds and of the river bank erosion in the channel of Totchè.

3 The Bathymetric Sampling Techniques

The bathymetric measurements of the bed of watercourses have been made in the dry season (low water period) thanks two simple techniques which take into account the section to be measured.

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 10m/s on a watercourse of 2.5 à 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.

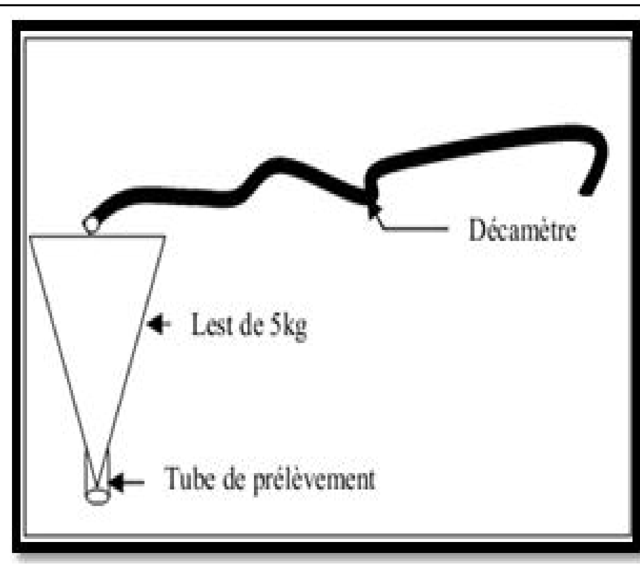


Figure 1: Thread weighted

The second technique consists to extend a graduated rope with the help of a pirogue, supported on both sides by stakes. This technique concerns the gauging of the bed and the bathymetry to low water period.

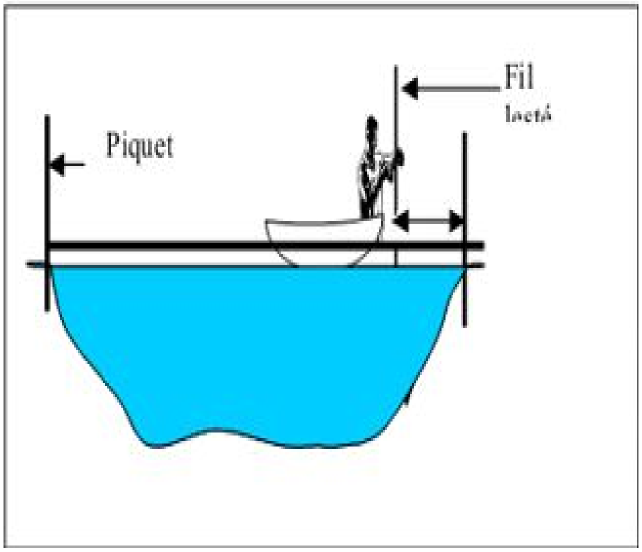


Figure 2: Technique of determination of bathymetry

4 Positions of the Cross-Sections in the Lagoon of Cotonou

The study of transport of sediments is particularly difficult since the bed of the river is continuously variable in time and space. The movement of sediments, which shapes the bed of the river, represents a relatively complex phenomenon.

To study the bed of the lagoon of Cotonou, we divided the lagoon into 12 sections rated from 0 to 11. The localization of these sections is presented on the following figure 3.

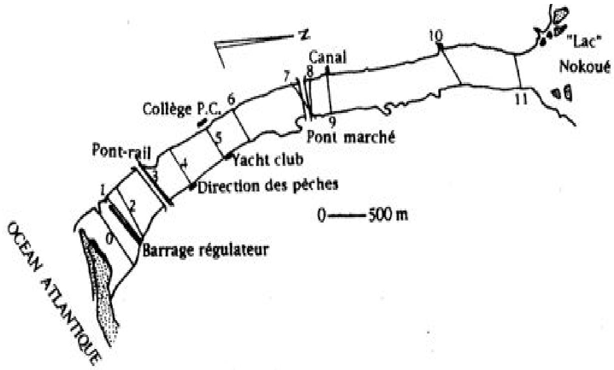


Fig 3: Positions of the sections in the channel of Cotonou

5 RESULTS AND DISCUSSION

5.1 Shapes in the River Bed in Each Section

The following figures present the shapes of each cross-sections of the lagoon of Cotonou.

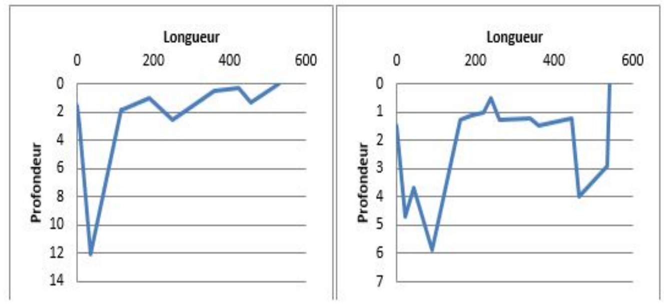


Fig 4: Bathymetric curves of the sections 0 and 1

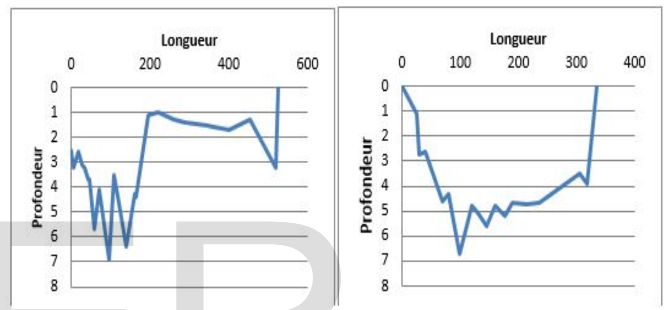


Fig 5: Bathymetric curves of the sections 2 and 3

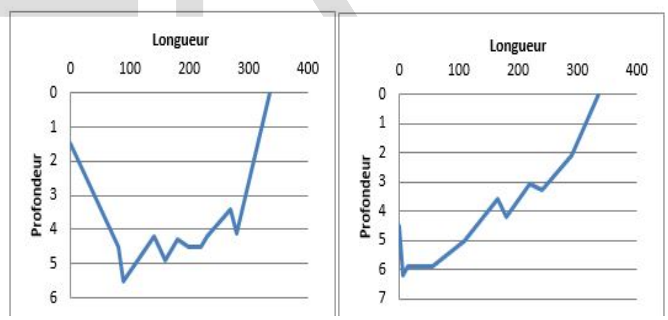


Fig 6: Bathymetric curves of the sections 4 and 5

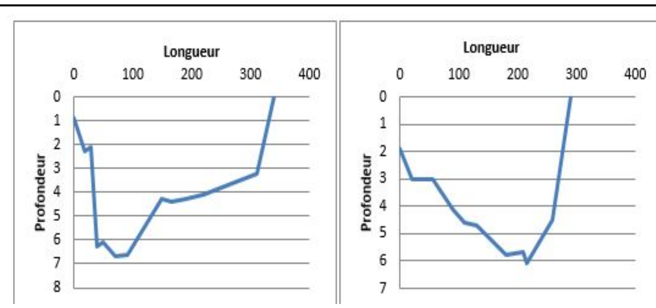


Fig 7: Bathymetric curves of the sections 6 and 7

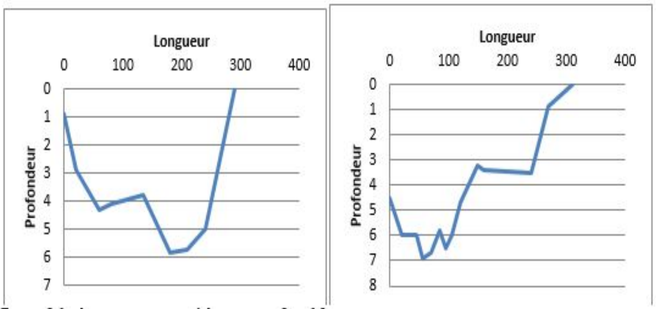


Fig 8: Bathymetric curves of the sections 8 and 9

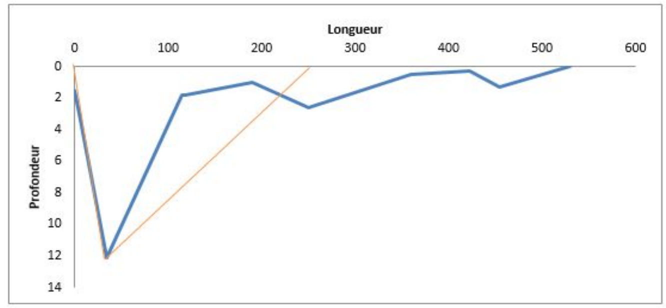


Fig 11: Assimilation of the bathymetric section to a triangle

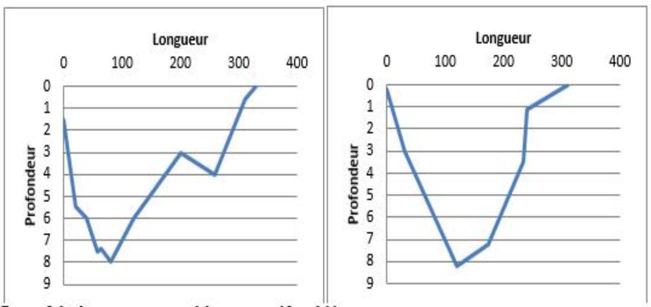


Fig 9: Bathymetric curves of the sections 10 and 11

5.2 Geometric Modelling

To study the geometry of the watercourse, we have assimilated the bathymetric curve of river to a figure of regular shape. So the following figures present the two chosen geometric models to represent the shape of the bed of the lagoon of Cotonou. The sections 3 to 11 will be assimilated to a trapeze and the sections 0 to 2 will be assimilated to triangle.

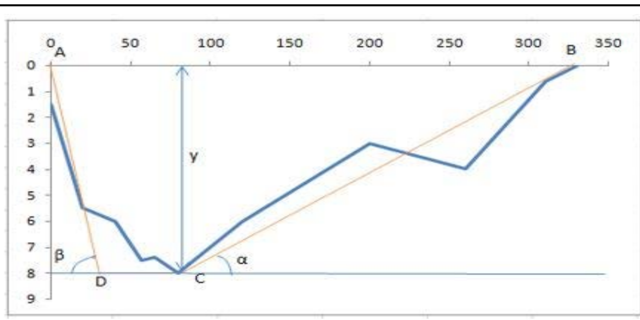


Fig 10: Assimilation of the bathymetric section to a trapeze

Let us consider that L_k is the width of glassywater of any section of the lagoon and l_k the width on top. If y_k is water draught of the lagoon at that section, then the wet area of the section may be calculated by the following formula:

$$s = y_k * (L_k + l_k)/2 \qquad (1)$$

5.3 Calculation of the Wet Area Of the Section

The following curve represents shape we got after the bathymetric measurement of one section of the lagoon of Cotonou (entry of the channel), using the geometric model, we got the width on top and the width to glassywater of each section, all along the lagoon of Cotonou. The determination of those dimensions allowed the modes of transport of the lagoon of Cotonou.

The obtained results of the width on top and the width to glassywater of each section, along the lagoon are shown in the following table (table 1)

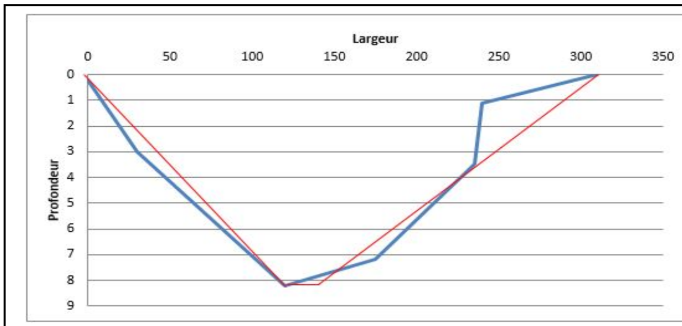


Fig 12: Assimilation of the bathymetric section to a trapeze

Table 1: Width on Top and to Glassywater of the Channel of Cotonou

Position of the section	Width to glassywater (m)	Width to top (m)	Height (m)	Area (m^2)
0	300	0	12.1	1815
1	540	0	5.9	1593
2	525	0	6.9	1811.25
3	335	84.2	6.7	1404.32
4	335	104.82	5.5	1209.505
5	335	81.3	6.2	1290.53
6	340	82.6	6.7	1415.71
7	290	100	6.1	1189.5
8	290	100	5.8	1131
9	310	27.19	6.9	1163.3055
10	330	50.31	8	1521.24
11	310	18.4	8.2	1346.44

6 Conclusion

The determination of the bathymetric data of the channel of Cotonou is an important step in the characterization of the hydrosedimentary dynamics of the estuary of Ouémé river in Cotonou. Those data are important to determine not only the solid transport by carriage but also to determine the suspended solid flow. That was the objective of the present paper which aims, to appreciate the shape of the bottom of lagoon of Cotonou. We remarked that, in function of the practiced velocities in the channel, the shape of the lagoon continously varies, comparing to the results of previous works on bathymetric data, in order to appreciate the evolution of the bottom of the lagoon of Cotonou.

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