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Characterization of periodic oxillations of the tide signal Observed in the Ebrie lagoon off the coast of Abidjan (Cote d'Ivoire)

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Abstract

Nowadays, rising water levels are a major factor threatening our coasts. We need to carry out more studies to better understand our coastal environment and obtain information in real time and continuously. It is in this context that this study was initiated. It consists of firstly showing the factors which make the coasts more vulnerable and then secondly showing the complementarity of the data at the different stations. We used data from two tide gauges (radar and float). The average level calculated at the fascinage and north quay stations during the different seasons varying from 0.95 m during low water periods to 1.12 m during flood periods, reveals to us that our coasts are more vulnerable in the rainy season and flood period. The determination of the duration of the flow and the ebb as well as the averages during these different seasons show that the data from a missing station can be replaced by the data from an existing station.

Keywords: Radar tide gauge; Tide signal; Periodic oscillations; Port harbor

1. Introduction

The study of tides is of paramount importance, enabling the accuracy of bathymetric probes, the determination of hydrographic datum, the creation of warning networks and the prediction of tides [7] ; [2]. It is also used for studies relating to the development of port infrastructures and coastal structures. In Cote d'Ivoire, few studies have been carried out on the determination of sea level components. The enlargement of the Vridi Canal has led to certain hydrodynamic changes. This has led to dynamic changes in the lagoon environment through the propagation of tidal waves. The characteristics of tidal waves in coastal environments are poorly understood. Coastal protection is becoming increasingly complex. Determining the characteristics of the tidal signal at Abidjan will provide a better understanding of our coastal environment. Hence the aim of this study, whose objective is to determine the main characteristics of tidal components during the different seasons observed in front of the Abidjan coastline.

1.1. Location of the study area

The tide gauge data recorded in the years (1985, 1995, 2019 and 2020) used to carry out this work came from two tide gauge stations (Figure 1). The Radar tide gauge (Quai Nord station) and the Float tide gauge (Fascinage station). - The Fascinage station is located on the east bank of the canal on the lagoon side, between latitude 005°15.999' N and longitude 004°01.206' W ; The Quai Nord station in the Ebrie lagoon is located between latitude 005°18.231' N and longitude 004°01.568' W, at the Port of Abidjan's Capitainerie.

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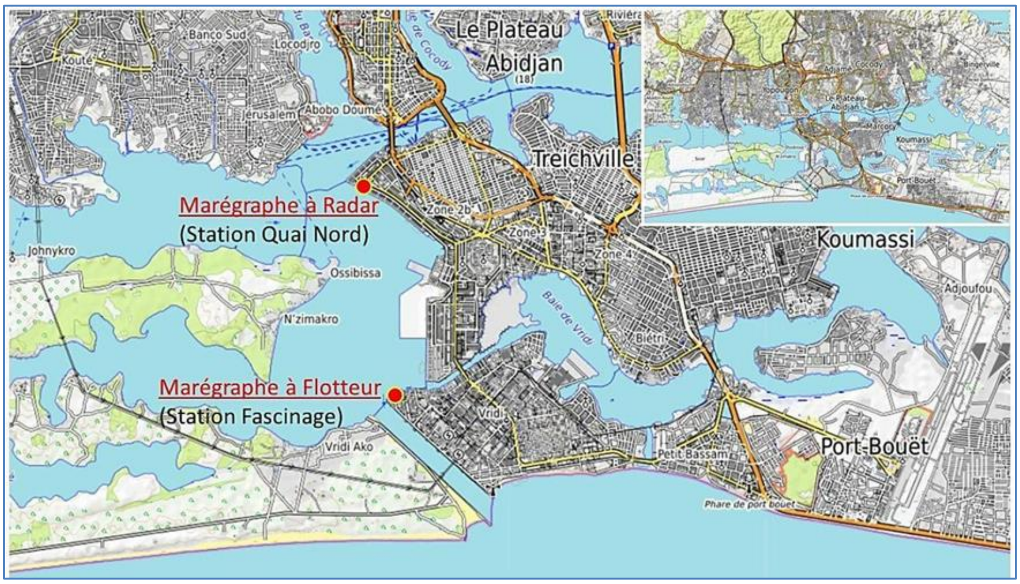

Figure 1 Location of tide gauges in the Port Autonome d'Abidjan

2. Materials and methods

2.1. Purchasing equipment

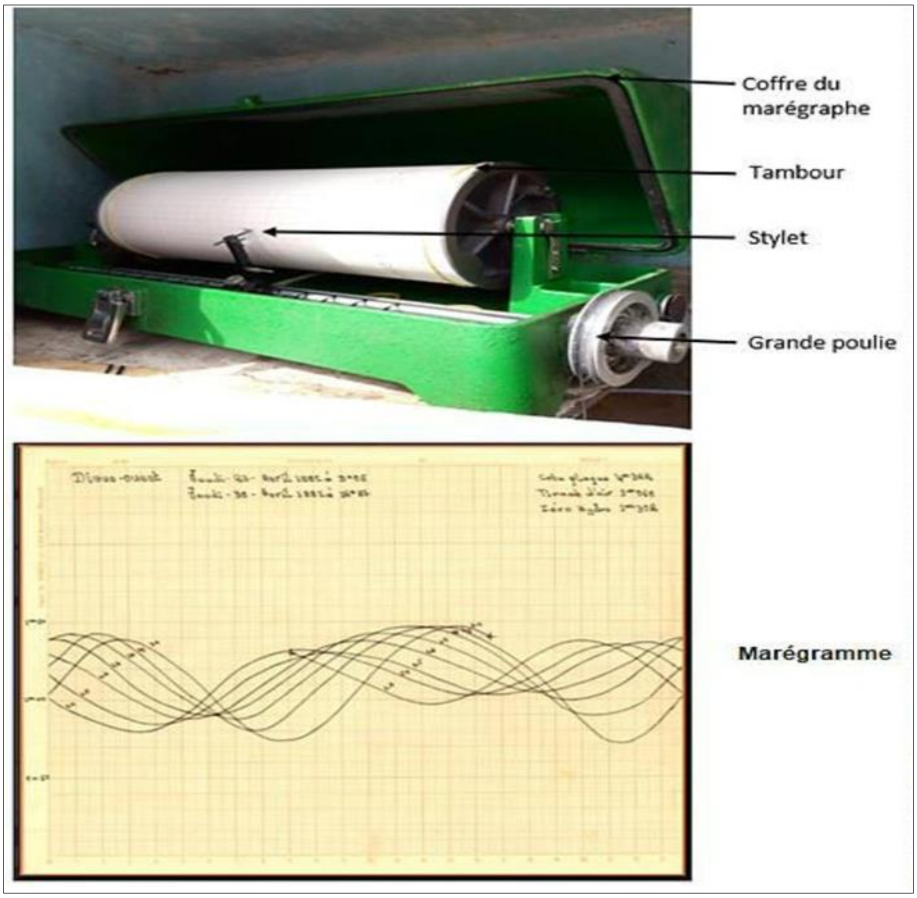

Figure 2 Components of a float tide gauge case and a tide gauge

The instruments used for data acquisition are float tide gauges and radar tide gauges. The float tide gauge has been in use since 1951, recording sea level as a function of time in the form of a curve traced on graph paper, known as a tide gauge. A stylus is used to trace the curve on a squared sheet of paper, wound onto a drum whose rotation is controlled by a clock (Figure 2).

The Radar tide gauge is also a water level measuring instrument that was installed in the port of Abidjan on December 17, 2018 (Figure 3). It replaced the digital tide gauge installed at Quai Nord. This type of tide gauge is used to record the data received from the radar in order to monitor the various water level measurements. The software starts automatically when the acquisition PC is switched on. Data is recorded in digital form and archived in monthly files.

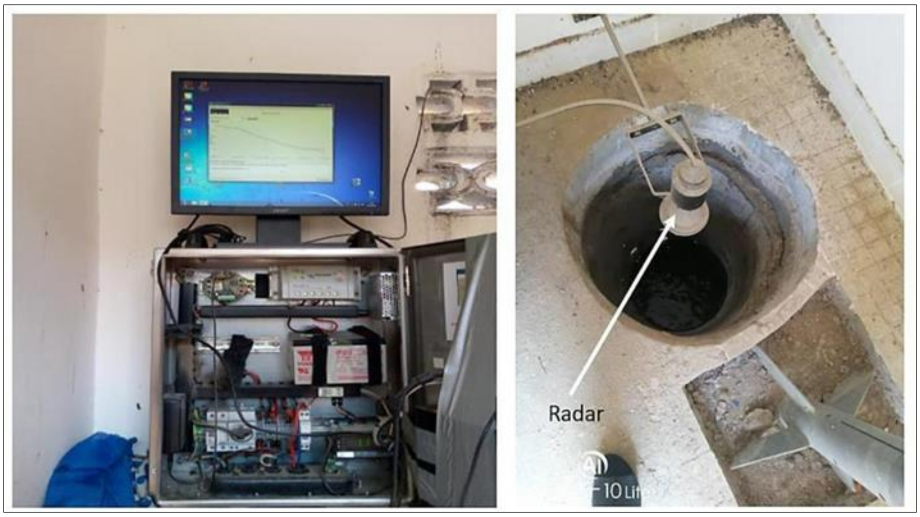

Figure 3 Radar tide gauge presentation

2.2. Harmonic analysis

This analysis extracts information from the deterministic oscillations of a time series of water levels measured by an astronomical instrument, the sum of which constitutes the tidal signal. Software or programs for harmonic tidal analysis are indispensable for anyone wishing to carry out an in-depth study of variations in sea-level components. The differences between these programs lie mainly in the definitions of the harmonic components and in the number of elementary waves taken into account in the analysis. For tide prediction, the Fortran Matlab program (T_Tide) by [5] was used to determine the harmonic analysis. This program provides a tide prediction with estimated errors.

2.3. Method for calculating the tidal coefficient

The tidal coefficient is obtained by the ratio of the amplitude M of the theoretical tidal range to the mean amplitude 2U of spring tides:

$$c = M/2U \times 100$$

U being the unit of height, characteristic of the port where the tide is to be calculated (U Canal de Vridi = 0.55 m), according to observations made by the hydrography and dredging department of the Port Autonome d'Abidjan. According to [1], tidal coefficients are best suited to assessing the size of the tide in an estuary by comparing it with the basic water level of the oceans.

2.4. Calculation of average monthly level

The monthly mean level is simpler to calculate: it is calculated by taking the arithmetic mean of the daily mean levels over a month. The PSMSL (Mean Sea Level Service) [6] recommends not calculating the monthly mean level when more than 15 days or more of data are missing during the month.

3. Results

3.1. Seasonal variation of the Tide Signal at Abidjan

Figures 4 and 5 show the variations in annual hourly water levels recorded at the Fascinage (1985) and Quai Nord (1995 and 2020) stations. Maximum water levels are observed in May, October and November. On the other hand, minimum levels are observed in March, July and August at both stations. The maximum water level at the Fascinage station is 1.12 m, and 1.17 m at the Quai Nord station. The lowest water level was observed in March, with a height of 0.49 m at the Fascinage station. On the other hand, at the Quai Nord station, minimum water levels are observed in March and August, with a height of 0.52 m.

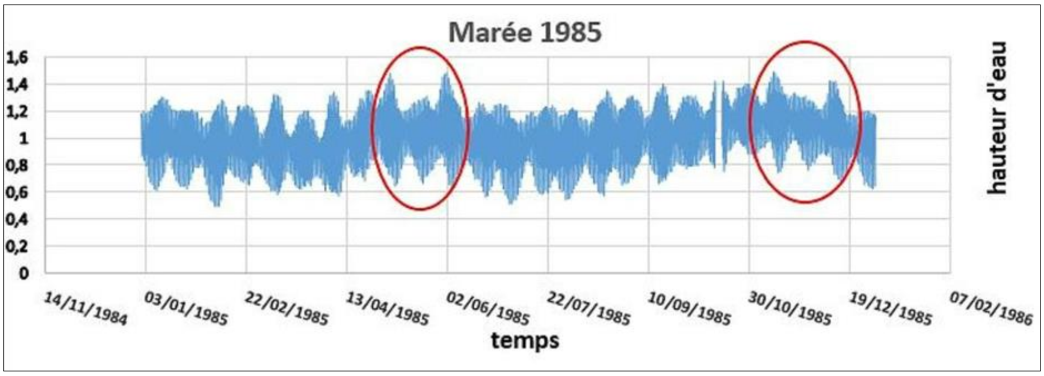

Figure 4 Variation in annual water level in the Port of Abidjan at the Fascinage station (1985)

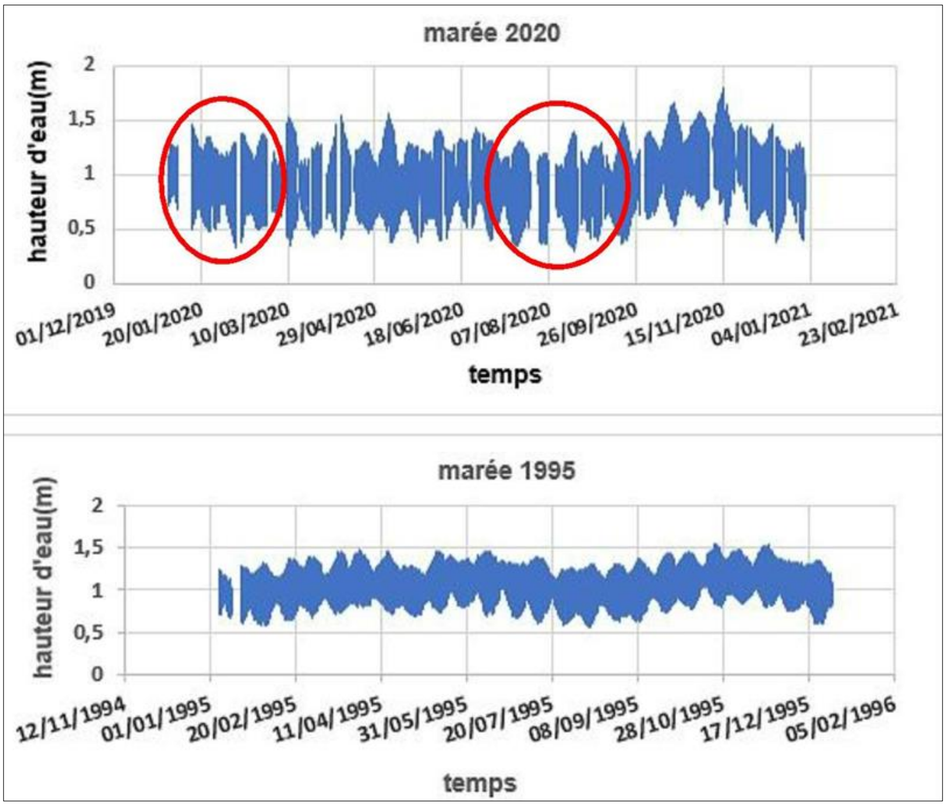

Figure 5 Variation in annual water level in the Port of Abidjan at Quai Nord station (1995 and 2020)

3.2. Determining the tidal coefficient

Tidal coefficients calculated in the Ebrie lagoon during the different seasons of 1985 at the two stations vary between 40 and 70 (Table 1). The highest tidal coefficients were observed during the low-water and rainy seasons, while the lowest coefficients were observed during the high-water periods at both stations. The high coefficient observed during the low-water period is explained by the fact that river water inflows into the lagoon during the low-water period are insignificant. The variation in water level in the harbor during this period is due to the inflow of water from the sea. During high-water periods, the quantity of water coming from the mainland is high, as the forces of the mainland and the sea confront each other. This explains the low coefficient observed during high-water periods.

Table 1 Tide coefficients at various stations

Name stations measurement	Low water period	Rainy season	Flood period
Fascination	60	61.81	40.98
North quay	60.36	65.45	54.54

3.3. Determination of high and low tides, mean water levels and annual averages for 985

Maximum high tides are observed in the rainy season and during flood periods, and minimum low tides during low-water periods at both stations (Table 2). The highest high water is 1.54 m, observed at the Quai Nord station during flooding. The rise in water level during these two periods is due to the large amount of river inflow. The drop in water level during low-water periods is due to the insignificant inflow of continental water.

Table 2 High and low tides for different seasons in 1985

Name stations measurement	Low water period		Rainy season		Flood period	
	Open sea	Low tide	Open sea	Low tide	Open sea	Low tide
Fascination Station	1.32 m	0.49 m	1.48 m	0.56 m	1.48 m	0.74 m
North Platform station	1.37 m	0.53 m	1.46 m	0.56 m	1.54 m	0.69 m
Difference water level	0.05 m	0.04 m	0.02 m	0	0.06 m	0.05 m

Table 3 shows the average water levels for the different seasons at both stations. Analysis of the averages shows that the highest water level is reached during the flood period (1.12 m), followed by the rainy season (0.99 - 1.02 m).

Table 3 Average water levels for different periods in 1985

Name stations measurement	Low water period	Rainy season	Flood period
Fascination Station	0.95 m	1.02 m	1.12 m
North Platform station	0.95 m	0.99 m	1.12 m
Difference water level	0 m	0 .03 m	0 m

Table 4 shows the annual mean at both stations. The average is 1.008 m at the Fascinage station and 1.004 m at the Quai Nord station, i.e. a difference of 0.004 m. Analysis of the annual averages at the various stations shows that the difference in water level at the tide gauge stations is minimal.

Table 4 Average annual water levels at various stations in 1985

	Fascination Station	North Platform station
Annual average	1.008 m	1.004 m

3.4. Determination of tidal range

Tidal range is the difference in water level between high and low water, and is relatively higher at the Quai Nord station than at the Fascinage station in all seasons (Table 5). However, the tidal range is lower during the flood period than in other seasons. Flooding strongly modifies the tidal signal in the Vridi canal estuary.

Table 5 Highest tidal ranges for different seasons at Quai Nord and Fascinage

Name stations measurement	Low water period	Rainy season	Flood period
Fascination	0.66 m	0.68 m	0.45 m
Quai nord	0.73 m	0.72 m	0.6 m

3.5. Flot and Jusant speeds

3.5.1. Flooding period

During periods of high water, the tidal wave shifts in height and time between the two stations (Figure 6). The tide arrives earlier with a higher height at the northern quay station than at the fascinage. This is due to the fact that river inflows oppose the tide and prevent the tidal wave from propagating normally. As the Quai Nord station is located in the lagoon, the maximum water level observed at this station is due to the fact that the Comoe river is closer to the lagoon than the sea, whereas the Fascinage station, located at the exit of the Vridi canal, is closer to the sea. The maximum tidal range during high water is 0.60 m at the Quai Nord station and 0.45 m at the Fascinage station, i.e. a difference of 0.15 m (Table 6). The speed of the flot is higher than that of the Jusant at Quai Nord, while at Fascinage the Jusant is higher than the Flot (Tables 6 and 7). The difference in water level is 0.15 m during the flood period, with a time lag of 1 hour.

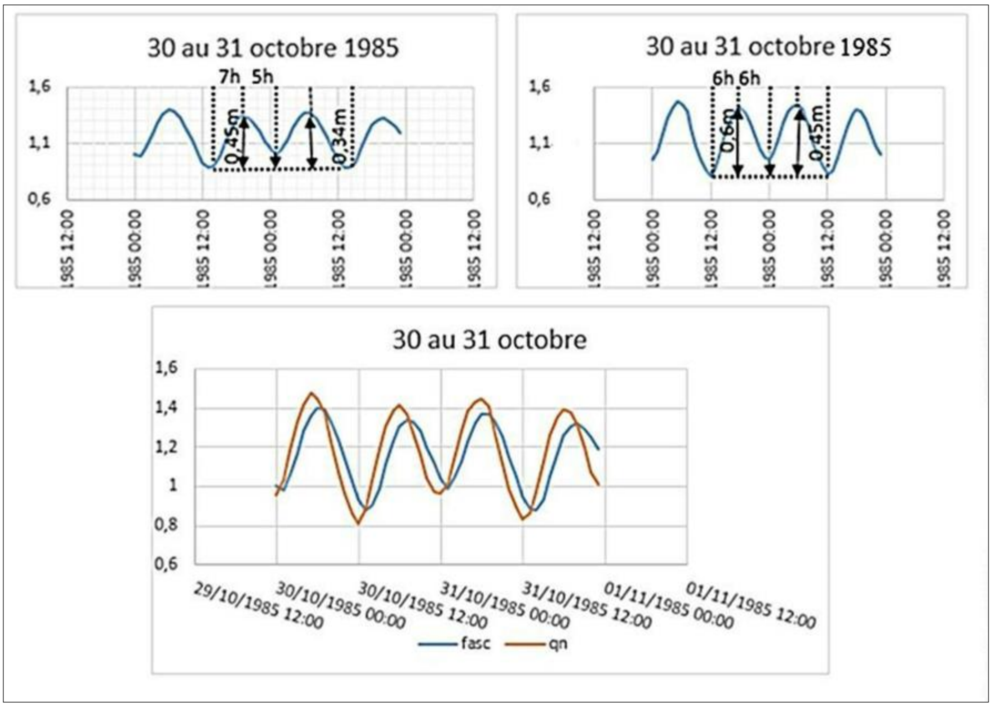

Figure 6 Changes in water level during floods

Table 6 Velocity of the Jusant and Flot rivers at the Fascinage station during flood periods

	Duration	Distance	Speed
Jusant	5 h	0.34 m	1.88.10-5 m/s
Float	7 h	0.45 m	1.78.10 m/s-5

Table 7 Velocity of the Jusant and Flot rivers at the Quai Nord station during flood periods

	Duration	Distance	Speed
Jusant	6 h	0.45 m	2.08.10-5 m/s
Float	6 h	0.6 m	2.77.10 m/s-5

3.5.2. Rainy season

The tidal offset is also observed during the rainy season (Figure 7). The tide always arrives earlier at the Quai Nord station than at the Fascinage, as the continental water masses are greater than the marine water masses entering the lagoon. During this period, the Jusant is faster than the Flot at both stations. The tidal range is 0.72 m at Quai Nord and 0.68 m at Fascinage, a difference of 0.04 m (Table 5). In contrast to the flood period, during the rainy season the Jusant velocity is higher than that of the Flot at both Quai Nord and Fascinage stations (Tables 8 and 9). The difference in water level is 0.14 m, with a time difference of 1 hour.

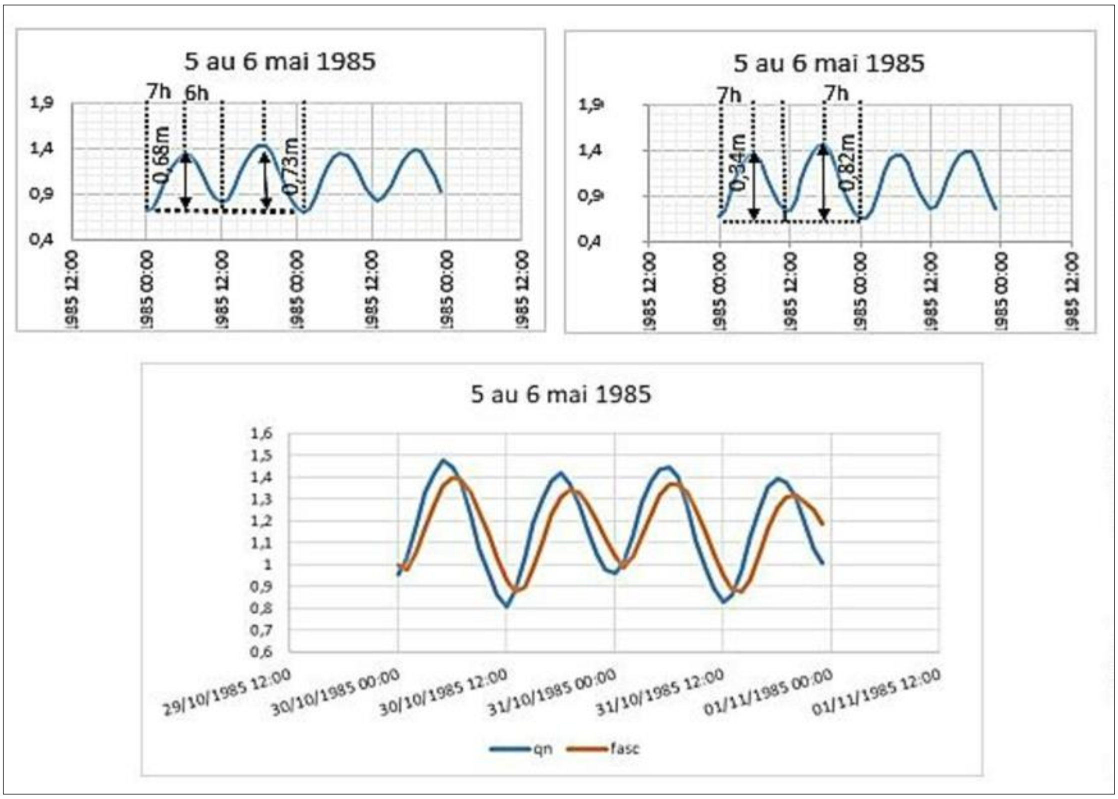

Figure 7 Water level changes during the rainy season

Table 8 Speed of Jusant and Flot at the Fascinage station during the rainy season

	Duration	Distance	Speed
Jusant	6 h	0.73 m	3.37.10-5 m/s
Float	7 h	0.68 m	2.69.10 m/s-5

Table 9 Speed of Jusant and Flot rivers at Quai Nord station during the rainy season

	Duration	Distance	Speed
Jusant	7 h	0.82 m	3.25.10-5 m/s
Float	7 h	0.34 m	1.35.10 m/s-5

3.5.3. Low-water period

During low-water periods, there is virtually no time difference, but water levels at Quai Nord are higher than at Fascinage (Figure 8). The difference in water level offset is very small, at 0.09 m. The tidal range at Quai Nord is 0.73 m and 0.66 m at Fascinage, a difference of 0.07 m (Table 5). Flot and Jusant velocities are relatively the same at the Fascinage station (Table 10).

However, at the Quai Nord station, the Jusant velocity is higher than that of the Flot (Table 11).

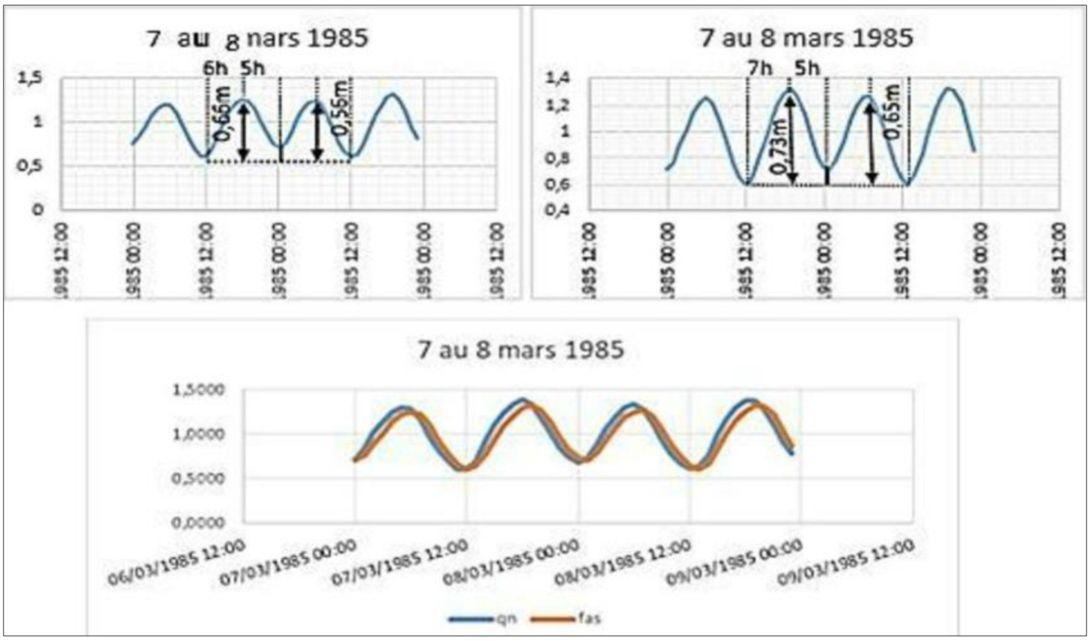

Figure 8 Changes in water level during low-water periods

Table 10 Velocity of the Jusant and Flot rivers at the Fascinage station during low-water periods

	Duration	Distance	Speed
Jusant	5 h	0.56 m	3.11.10-4 m/s
Float	6 h	0.66 m	3 .05.10 m/s-5

Table 11 Velocity of the Jusant and Flot rivers at Quai Nord station during low-water periods

	Duration	Distance	Speed
Jusant	5 h	0.65 m	3.61.10-4 m/s
Float	7 h	0.73 m	2.89.10 m/s-5

Determining the difference in water level and time offsets shows that missing data from one station can be recovered by adding or subtracting the difference in water level and time.

4. Discussion

This study revealed the periodic oscillation of the tidal signal and the factors influencing water level variations at different seasons of the year. The 1985 water level at the Fascinage and Quai Nord stations ranged from 0.95 m at low water to 1.12 m at high water. During low-water periods, water levels are controlled by the inflow of sea water, while during flood periods they are dependent on the inflow of continental or river water. These movements at different times of the year considerably modify the parameters or factors inherent in tidal signals. The results of our work are corroborated by the studies of several authors who have worked on tide gauges covering different years. The work carried out by [8] in the Port of Abidjan shows that during the low-water period, the level of marine water entering the lagoon is higher than the quantity of continental water, and that during this period water exchanges from the sea to the lagoon. According to [3], marine influence is almost non-existent during flood periods and strong during low-water periods at the mouth. Tano [9], for his part, showed in his work during the period from 1982 to 1988 that the tidal variability recorded by the Port Autonome d'Abidjan tide gauge station presented exceptional values exceeding 1.7m, with oscillations ranging from 0.3m to 1.7m. In his opinion, this difference in amplitude could be explained by the quality of the data used by these authors. High water levels can lead to flooding/partial submergence when the slope of the coast is not steep. Mahan [4] showed in their work that the evolution of the water level at the Quai in the Port of San Pedro is higher, with water levels above 1.2 m, than in the Fishing Port, where water levels were less than or equal to 1.2 m. In their view, water levels at the Quai in the Port of San Pedro were higher than in the Fishing Port, where water levels were less than or equal to 1.2 m. For them, the extreme water levels reaching 1.7m coincide with the first week of September, which marks the start of the rainy season in the southwest. The Comoe is therefore the biggest contributor of liquid flow to the Ebrié lagoon.

5. Conclusion

The tidal signal was studied in three parts, according to the different seasons of the year. It showed us that the tidal signal has two maximum water levels observed in the rainy season and flood period, as well as two minimum water levels in the low-water period. Tidal coefficients calculated for the Abidjan lagoon in 1985 at the two stations ranged from 40 to 70. The highest tidal ranges were observed during the low-water and rainy seasons, with flow velocities practically higher than those of the ebb tide. This study showed that the tidal signal was virtually identical at all stations. It also showed that during low-water periods, the inflow of sea water into the port of Abidjan is greater than the inflow of river water, whereas during high-water periods, the opposite phenomenon is observed. The analysis of annual averages at the various stations shows that the difference in water levels at the two stations is minimal, and that of hourly shifts in water level heights has shown that data from a missing station can be substituted by data from an existing station by adding the difference or subtracting the difference in water level heights. The averages for the different seasons show that the coasts are more vulnerable during the rainy season and the flooding period.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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