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Hydrological and Morphological Characterization of the Sô River Basin in South-East of Benin (West Africa)

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ABSTRACT

As a prelude to a large ecological quality assessment study, the Sô River, a watercourse in southern Benin, has been characterized on the hydrological and morphological levels. The study was conducted for a year from June 2015 to May 2016 with a monthly frequency of data collection. At the end of this large sampling campaign, the determination of the long and cross-sectional profiles of the Sô River made it possible to clearly distinguish a upper course, an average course and a lower course, all characterized by morphological and riverine diversity. These sectors have particular biophysical characteristics. The representation of the bathymetric map of the river shows an average depth of 3m and a maximum of 6.5m. Finally, river flow facies have some general structural and functional uniformity in terms of current velocity, bathymetry, substrate particle size, bed slope and cross-sectional profiles. All this militates in favor of a dynamic equilibrium of the Sô River reflecting a good hydro-morphological state except for its slightly disturbed lower course.

Key words: *Hydrology, Morphology, Bathymetry, Basin, Sô River, Benin.*

INTRODUCTION

If man has always relied on the river for his economic and social development (food and energy source, a privileged transport route), he has had it over the centuries and for his own needs. Sometimes in a manner incompatible with good ecological status[1]. The good ecological status of watercourses is that which provides the conditions necessary for the life and free circulation of species and sediments and the autonomous regulation of hydrological regimes[2,3,4].

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For a river to reach this state requested by [5], it must satisfy three quality criteria: hydro-morphological, physico-chemical and biological. These three quality criteria play a decisive role in the aquatic species reception capacities. The study of the hydro-morphological quality of the rivers constitutes therefore a first step towards an ecological evaluation, precedent of course the chemical and biological quality of the waters.

In South-east of Benin (West Africa), mainly in the Sô River watershed, there are some activities that can influence its physical quality: agriculture, forestry, the absence of a sanitation system and waste treatment, intensification of wild waste deposits on banks, construction of latrines on the banks etc. Moreover, the numerous branches used for the realization of the acadjas are left in the river after the exploitation.

No special provision has been made by the authorities in charge of the management of the Sô River to prevent the dumping of waste from both occasional riparian markets. On the contrary, there is an increase in waste-generating activities in Sô-Ava, which contributes to worsening the degradation of this river. This situation suggests that, in the long run, the loss of part or even filling of this river could be seen, as has been observed in several watercourses and water bodies in Africa[6,7,8].

In view of this anthropization of the Sô River and its watershed, understanding its river dynamics is essential in order to account for the physical quality of this environment, which guarantees the sustainability of biodiversity since biological systems are conditioned by the structure of the physical environment. This is an original and highly relevant work to optimize the acquisition of biological data.

MATERIELS AND METHODS

Study area

The Sô River is 84.4 km long and has a catchment area of approximately 6.42 km^2 and is between 6 °24' and 6°32' North Latitude and 2°27 ' and 2°30' Longitude East. It is located in the municipality of Sô-Ava, municipality to which it owes its name. It takes its source in Lake Hlan and is connected to the Oueme river by backwaters. This river is one of the old arms of the Oueme river, which has since detached itself, and which pours its waters northwest of lake Nokoue to the level of the lake city of Ganvié[9]. Throughout the basin of this river, the local inhabitants practice important agricultural activities (potatoes, cassava, maize and crops) requiring the use of fertilizers and the raising of pigs and oxen left in ramming along the banks. Similarly, for their fishing activities, many branches are used to make the acadjas that abound the river and finally the fraudulent traffic of the hydrocarbons which is observed daily are as many anthropic activities that develop in this environment. These various demographic and anthropogenic pressures affect directly or indirectly the quality of its waters.

Basin prospecting: The first phase of the study consisted of a large basin survey carried out for three months and selected the various sampling stations according to several factors, the most important of which were pollution outbreaks and Points of confluence with the various tributaries of the river Sô.

Choice of study stations: In order to determine the variability of the environmental parameters, twelve study stations were selected (Fig. 1), taking into account the longitudinal stratification proposed by [10]. The stations were chosen for accessibility at the station, the presence or absence of urban agglomerations, the existence of agricultural activities or a potential source of pollution, the diversity of the biotope and the presence or the absence of the coastal vegetation. These characteristics make it possible to refine the spatial portrait of the quality of the water along the river. Table 1 presents the geographical coordinates and characteristics of the selected stations.

Table 1: Geographic coordinates characteristics and description of sampled sites

Sites	Names	Geographical coordinates	Characteristics of the stations
ST1	Vêky	N07°16’98.4’ ’; E002°35’82.2’’	To assess the impact of Lake Nokoue (the largest estuarine complex in Benin) on water quality and the composition of biological communities.
ST2	Sindomey	N07°15’84.3’’ ; E002°32’50.0’’	Place of unloading of petroleum products and other hydrocarbons from Nigeria.
ST3	Dogodo	N07° 18’40.2’’ ; E002°33’56.3’’	Evaluate the impact of sand mining on the physical, chemical and biological integrity of the river. Strong presence of wild garbage deposits.
ST4	Ahomey-Gblon	N07°22’65.2’’ ; E002°34’02.2’’	Evaluate the impact of excreta of pigs and oxen directly dumped into the river. Evaluate the impact of wastewater from the collector on water quality and composition of the lake biological community.
ST5	Ahomey-Ounmey	N07°25’40.3’’ ; E002°33’79.1’’	Many disruptive activities, especially waste from agriculture. These sites receive inputs from the various branches of the river that cross several cities and within which are carried out daily activities of washing motorcycles, bathing, washing, dishes, etc.
ST6	Ahomey-Lokpo	N07°27’28.3’’ ; E002°33’17.7’’	
ST7	Zoungomey	N07°29’86.2’’ ; E002°33’78.3’’	
ST8	Kinto Oudjra	N07°33’84.3’’ ; E002°35’81.2’’	
ST9	Togbota	N07°39’40.6’’ ; E002°34’81.3’’	The immediate catchment area is uninhabited and is completely occupied by semi-aquatic vegetation. There is also a small creek draining the neighborhoods (Togbota and Tota) which carries a diversity of waste and sewage from households surrounding the river at this location. The near side is uninhabited and there are no streams flowing into the river at this level.
ST10	Tota	N07°40’98.2’’ ; E002°38’99.8’’	
ST11	Rhlampa	N07°48’45.4’’ ; E002°37’47.9’’	Control sites with little influence of polluting human activities compared to previous sites. Site located upstream of the river receiving the waters of the Oueme river during periods of flood
ST12	Djigbé-Ovo	N07°52’96.2’’ ; E002°35’99.8’’	

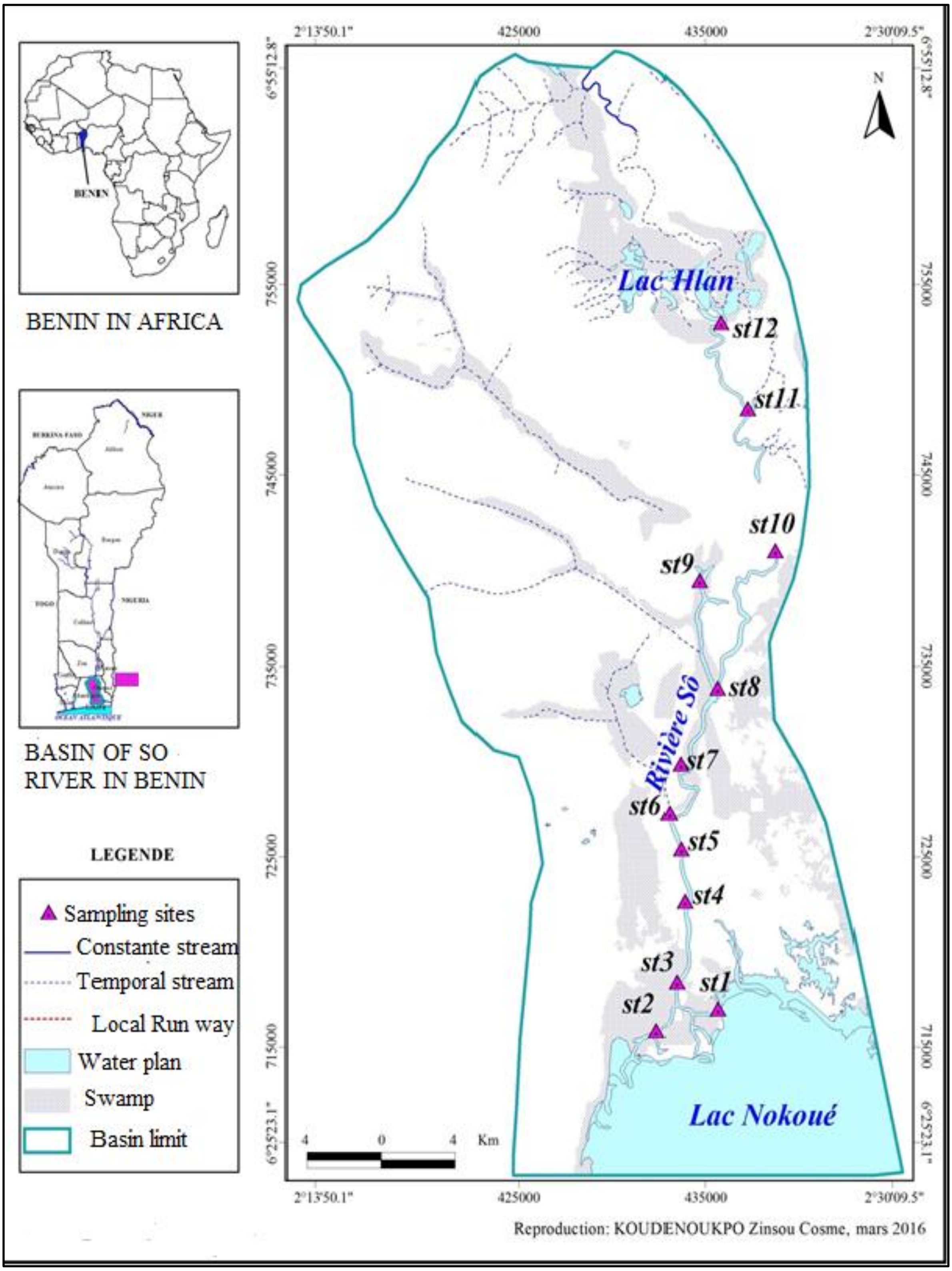


Fig. 1: Map of the Sô river basin and sampling stations

Data collection: The second phase, from June 2015 to May 2016, consisted of the measurement of hydrological, morphological data and the sampling of the substrate at each station.

Measuring the long profile and calculating the slope

The long profile designates the line joining the lowest points of a watercourse from its source to its mouth. The general appearance always has a more or less regular hyperbolic shape, the slope of the upstream parts being much greater than that of the downstream parts [11]. It is from this longitudinal slope that the speed of water flow and the delimitation of the upper, middle and lower courses will depend.

The long profile was made from two distinct parameters: the altitude and the distance separating the site from the source zone. The long profile is thus obtained by plotting the distance of the watercourse (expressed in km) along the y-axis and the different altitudes (expressed in m). These data were supplemented by observations made directly during the field trips. Each time, the slopes were calculated using the formula[2]:

$$p = \frac{Y_B - Y_A}{X_B - X_A}$$

with YB-YA is the distance from point B to point A and XB-XA is the distance from point B to point A.

Cross-section or transversal section

Two stakes are planted on both banks and are connected by a tight graduated string. A bracket adjusts the string horizontally. Using a graduated plumbing rule, the heights of the water column and the sludge are determined from one bank to the other by following the graduation of the string and taking care to maintain the same equidistance between two measures. The data thus obtained made it possible to determine for each site the gridded cross section on millipeter paper and the average depths of the sludge. The wetted section is expressed in m^2.

Flow velocity

The surface velocity (Vs) of the water was measured according to the method of Adandédjan[12]. It consists in timing the time taken by a float to travel a distance of 1 m measured at the decameter. This exercise was repeated three times. The speed is then equal to the distance traveled (1m) relative to the average time (in seconds). The velocity of current Vc is drawn according to the relation[13]: Vc = 0.80 × Vs; It is expressed in (m/s).

Water flow

The flow rate indicates the volume of water discharged at a point of the watercourse per unit of time. The climate of the region, the permeability of the terrain and the slope affect the flow, the subsequent irregularities of which result in floods and low flows in their rhythm and consequence according to the water supply method[14]. The higher the flow rates, the faster the transport and dilution; Heterotrophy and sedimentation are displaced downstream[15]. The flow rate is calculated according to Angelier[2] from the formula:

Q = V* S with V = Flow rate in m/s; S = Wet section in m^2 and Q = Flow rate in m^3/s

Granulometry

At each site, one, two or three samples were harvested, sometimes organized as transects. These transects were established to determine the spatial variability of the substrate size within a site, either by taking different samples at variable distance from the shoreline along a single transect, or by considering several of these transects located a few meters from each other from upstream to downstream on the same site. The substrate was collected using an Eckman type bucket (Fig. 2).

Fig. 2: View of the Ekman type bucket

This material can harvest 5 to 10 kg of substrate. Each sample was taken at the bottom of the river and the analysis of the large substrate (> 31.5 mm) was carried out on the ground. Sediments less than 31.5 mm in diameter were transported to the laboratory for drying and sieving.

In the laboratory, each sample was transferred into containers to dry for 1 to 2 weeks. Since most samples contain very little organic matter, they have not been destroyed. Dry sieving of the substrate was carried out using the sieves of different meshes according to the Wentworth scale.

Statistical treatments

The Kruskal-Wallis test was used to measure the variability of parameters from one sector of the river to another. The SNK test made it possible to compare sectors taken two by two. All the statistical analyzes carried out were carried out with software R version 2.15.3 with the FactoMineR package.

RESULTS

Morphology of the bottom of the Sô River

The detailed analysis of the bathymetry of the Sô river reveals maps with a morphological diversity with depths varying between 2 and 6.5 m, which is an average of about 3 m (Fig.3). In general, the depths increase from the upstream to the downstream of the river. The highest depths (5 to 6.5 m) are observed at the downstream part of the river.

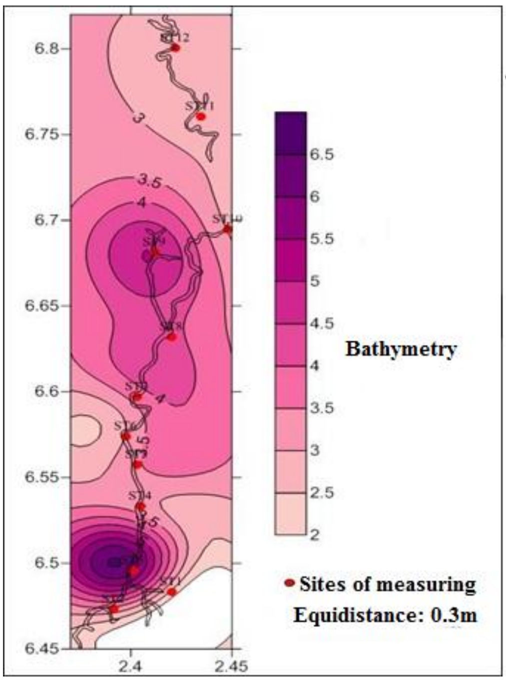


Fig. 3: Bathymetric map of the Sô River (Conception: Koudenoukpo, 2017)

Long profile of the Sô river

The long profile of the Sô River (Fig. 4) is typical of that of lotic environment. It is relatively concave and presents three zones of different slopes. The upper course, of steep slope, extends from the source upstream of station ST5. The average course of low slope, goes from the station ST5 to the station ST8 and the lower course of slope also lower, from station ST8 to station ST12 which ends in lake Nokoue.

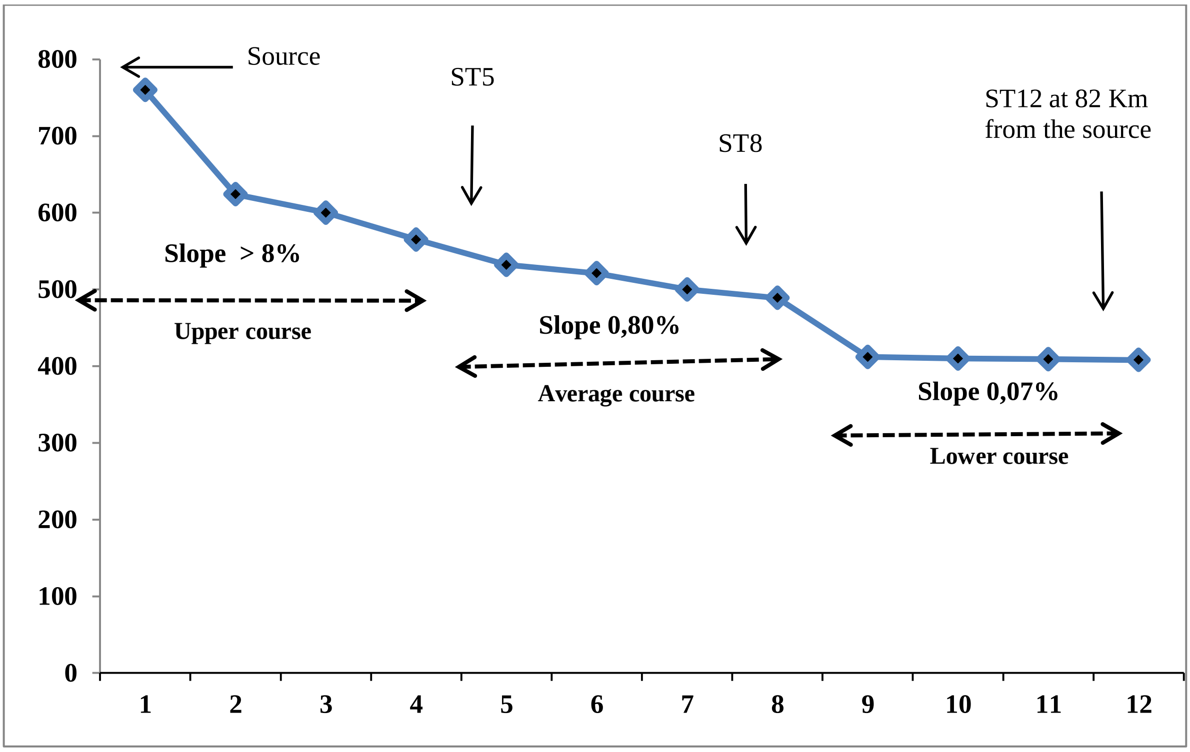


Fig. 4: Long profile of the Sô River showing the different sectors

Observation of the long profile of the Sô River (Fig. 4) reveals 3 sections of relatively different slopes. The steepest section (8.89%) extends about 640 m, from the source to the entrance of station st5: it is the upper course of the river Sô. The average slope (0.80%) constitutes the average course of the Sô River with an estimated length of 1360 m: this is the average course. Finally, the lower course, which constitutes the last section, has a slope of 0.07% and a length of about 3250 m.

Cross-section

These Fig. 5, 6 and 7 show the cross sections of the lower, average and upper course of the Sô River, respectively. Lower course stations (Fig. 5) have widths between 57 and 76 m, with sediment height slightly lower than that of the water column. As for the stations of the average course (Fig. 6), they have a width between 82 and 171m and a balance between the height of the water column and that of the sediments. Finally, at the stations of the upper course (Fig.7), there are widths between 11 and 29 m and a clear superiority of the height of the column of water over that of the sediments.

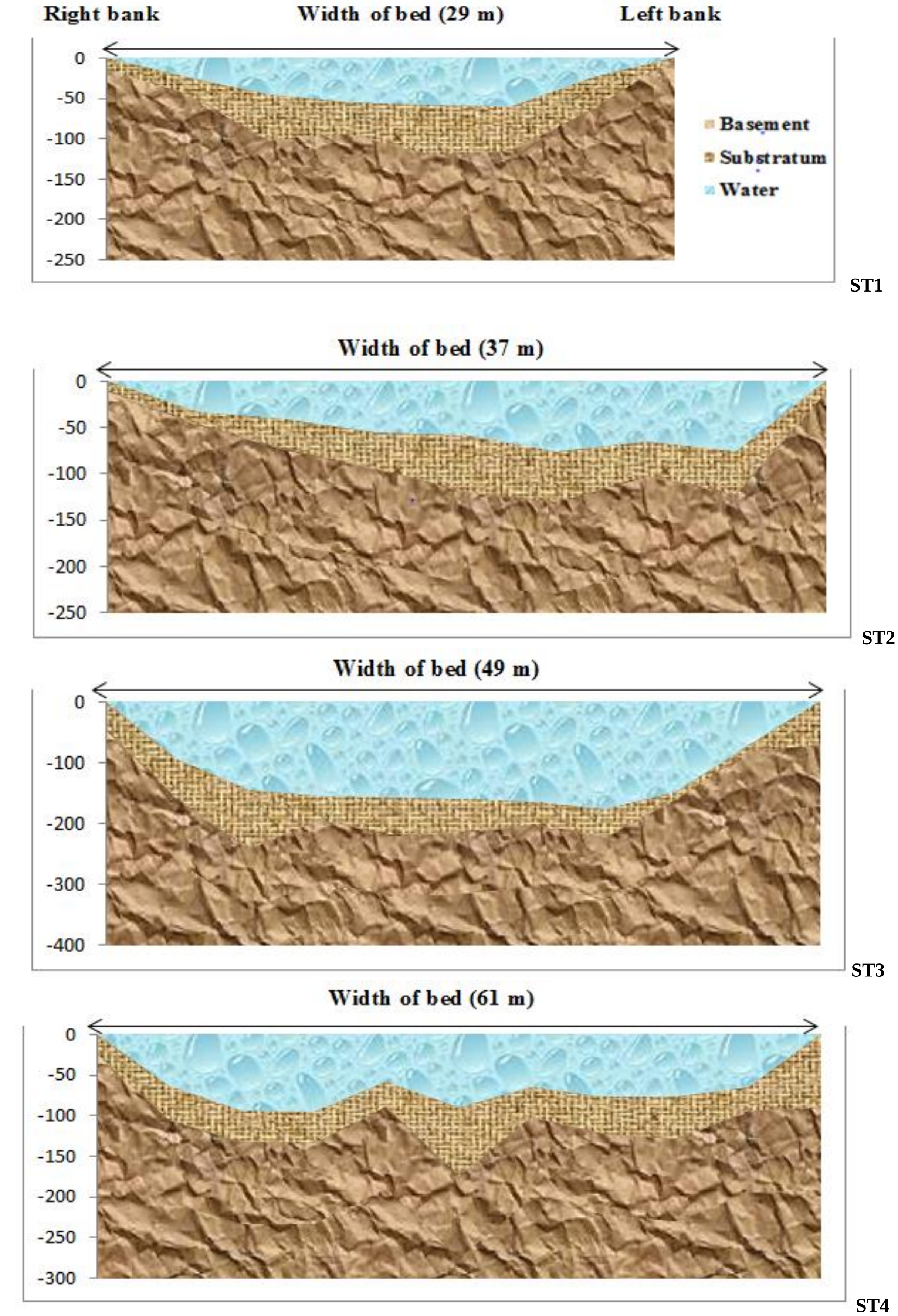


Fig. 5: Cross-sections of stations in the lower course of Sô River

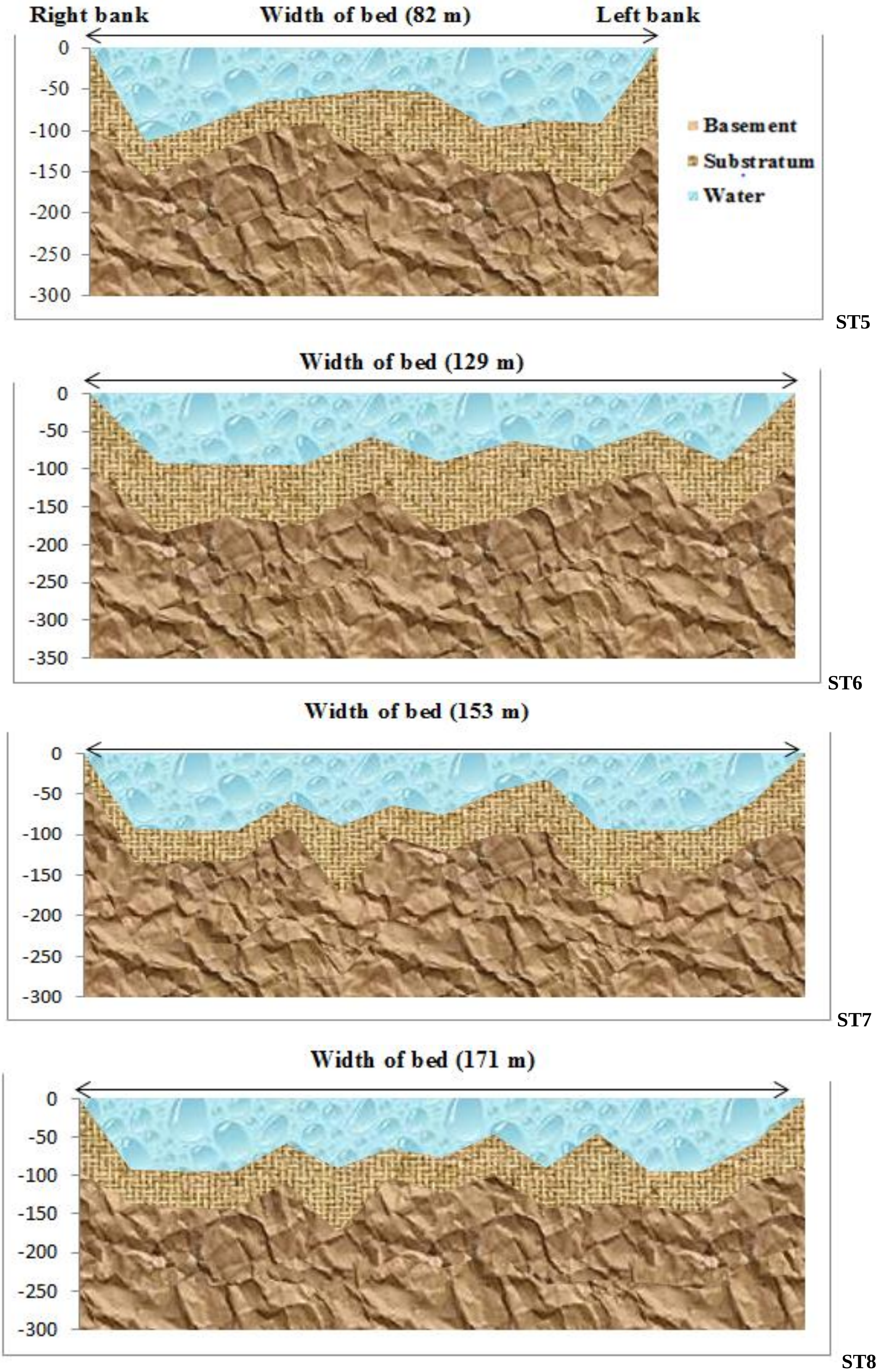
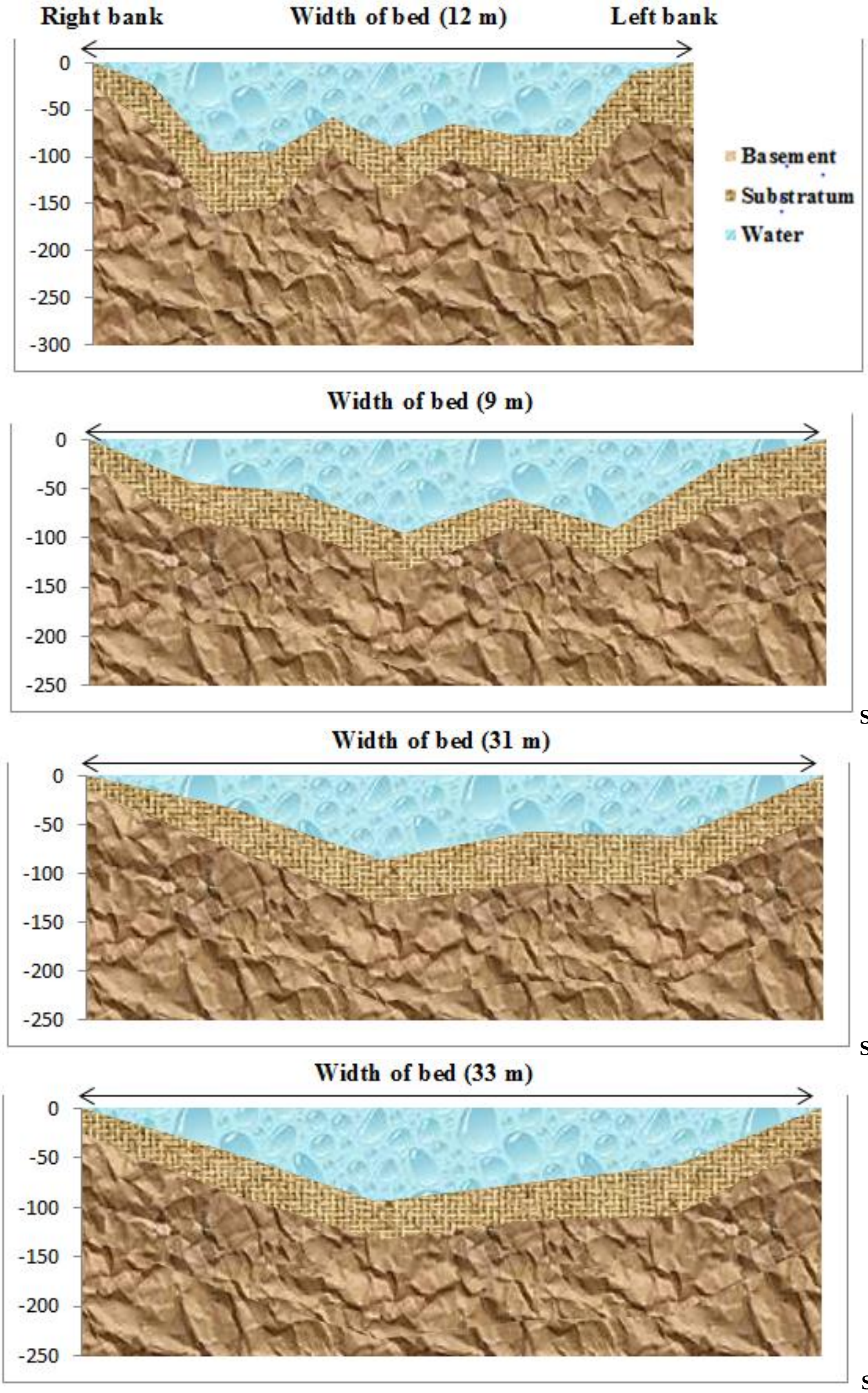


Fig. 6: Cross-sections of stations in the middle course of Sô River



ST9

ST10

ST11

ST12

Fig. 7: Cross-sections of stations in the upper course of Sô River

Granulometry

The proportions of the substratum types obtained in the Sô River are shown in Fig 8. The results of the particle size analysis of the substrates by station are shown in table 3. Four facies of greyish to blackish color substrates were determined in the Sô River. These are sand, mud, muddy sand and sandy mud. The proportions of clay and organic matter are respectively less than 3 and 2% in all the substrates.

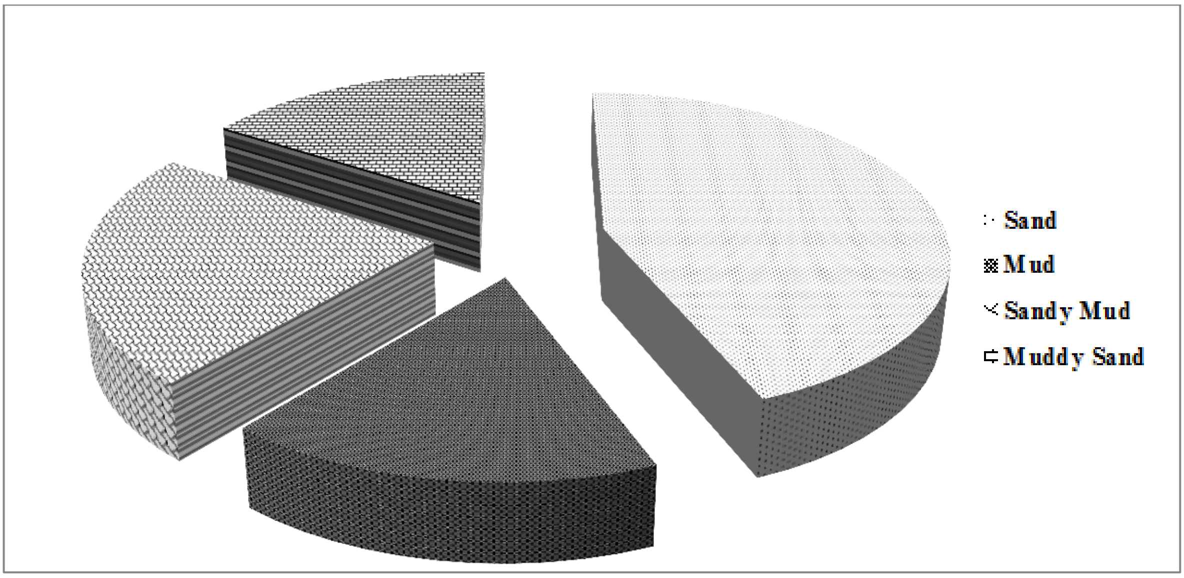


Fig. 8: Different substrate facies at the bottom of the Sô River

Table 3: Particle size distribution and nature of the substrates of the different sampling sites in the Sô River during the study period. C = clay; S = silt and OM = organic matter)

Sites	Colors	Granulometry		Classification
		% Sand	% Mud (C+S+OM)	By Caissie (2000)
ST1	Greyish	3.71	96.11	Mud
ST2	Greyish	28.15	71.04	Muddy-Sand
ST3	Brownish	90.86	4.17	Sand
ST4	Blackish	82.13	7.13	Sandy-mud
ST5	Greyish	84.62	9.06	Sandy-mud
ST6	Greyish	63.17	14.63	Sandy-mud
ST7	Greyish	28.14	71.25	Muddy-Sand
ST8	Greyish	65.49	18.37	Sandy-mud
ST9	Brownish	93.01	4.16	Sand
ST10	Brownish	91.44	5.19	Sand
ST11	Brownish	94.03	3.27	Sand
ST12	Brownish	92.51	5.92	Sand

Hydrological parameters

Table 4 summarizes the hydrological data for the three sectors identified from the completion of the long profile of the Sô River. The wet section is globally increasing from the upper reaches of the Sô River to its lower course. It should be noted, however, that the wetted section in the lower course is less than that of the middle and upper reaches, implying an acceleration of the flow velocity in these areas. The current velocity varies and the water flow varies very significantly from one sector of the river to another ($p < 0.001$). The flow velocity at study stations varies irregularly from upstream to downstream (Table 4). It decreases as one moves away from the source zone, which is explained by the location of the upper reaches of the river where the slope is higher (8,89%). The water flow of the Sô river gradually decreases from the source to the lower course with a highly significant variation ($p < 0.001$).

Table 4: Mean values of the hydrological parameters measured in the three sectors of the Sô River during the study period (UC = Upper course, AC = average course, LC= average course)

Hydrological parameters	UC	AC	LC	Significance
Wet section (m^2)	$127.4^{\mathbf{a}}$	$62.7^{\mathbf{b}}$	$29.57^{\mathbf{c}}$	***
Current of velocity(m/s)	$0.62^{\mathbf{a}}$	$0.51^{\mathbf{b}}$	$0.4^{\mathbf{c}}$	***
Debit (m^3/s)	$79.01^{\mathbf{a}}$	$32.11^{\mathbf{b}}$	$11.83^{\mathbf{b}}$	***

DISCUSSION

The representation of the bathymetric map of the Sô River shows that the average depth of 3 m and a depth of less than 2 m on 31% of the surface of the river. The deepest zone (6.5 m) is located at the level of the downstream sector. This sharp increase in depth is related to the exploitation and marketing of lagoon sand in this sector of the river. The bathymetry of the Sô river shows characteristic values of deep watercourses, which is favorable to the constitution of diverse habitats favoring high biodiversity[16,2,17,18,19]. In addition, the approach for determining the long and cross-sectional profiles is very useful for answering scientific questions, in particular the state of filling of ecosystems on the one hand and bank erosion on the other hand[20]. The Sô river is characterized by three different sectors (lower, average and upper) with a morphological diversity and riverine styles. The upper course of the Sô River show an equilibrium profile with a steep slope (8.89%). The lithology is an explanatory factor of this type of relief because it derives from the greater or less solidity of the rocks constituted essentially of granite [21]. In this sector of the river, the flow of water is fast with a lot of mineral matter in suspension or rolling on the bottom of the stream. This rapid flow of water allows an increase in dissolved oxygen levels, which is favorable to the growth of aquatic organisms[2,22, 23].

In the average course, the Sô river slows down its course, widens and its depth increases. The waters are increasingly loaded with suspended organic matter (microalgae or coloids) and dissolved (mineral salts and clays), which come from the leaching of the soils of the watershed. This facilitates the slowing of the current, a greater diversity of habitats, thus allowing the development of a diversity of living beings[24,25,22,26].

Finally, in the lower course of the Sô River, fed by its numerous tributaries, there is a narrowing of the width of the bed and the strong thickness of the substrate. This could be explained by the loading of waste and various particles, erosion and leaching of the banks, which lead to an accumulation of sediments and other elements at the bottom of the river, thus reducing its depth. There is also an increase in bed width and water flow. This could be explained by lateral water flows from the tributaries and exsurgences. [16] emphasizes in this connection that, in receiving small tributaries, the wetted section is bound to increase. In addition, the progressive decrease in water velocity, correlated with fluvial erosion and non-native and indigenous inputs of organic particles and detritus, would explain the increase in sludge thickness in lower river of the Sô river. Indeed, when the thickness of the water column becomes lower than that of the substrate, there is a risk of filling even if it is not visible at the level of the human species[27]. The same observations were made at the mouth of the Sasandra river in Côte d'Ivoire[21]. [28] point out that this longitudinal diversity of forms and their physical structure is very beneficial and can be exploited by the flora and fauna which meet the different habitats necessary for the completion of their vital cycles and to their proliferation in the environment.

In addition, it is important to understand the importance of substrate size, particularly sediment content, for aquatic habitat. The results of this study showed a high variability of the substrate content. Whatever the environments in which the samples were taken, the sedimentary particle size shows a certain diversity with a predominance of the sand on the other substrate facies. The predominance of sand is explained by the inert drift observed during the flood period in this river[2]. This variability is not only a function of the various anthropogenic activities developed along the watershed, but also of the composition of the geological substratum of the basins[1]. The same results were found in the Gombe, Kinkusa and Mangengenge rivers in the city of Kinshasa in Congo[26].

Finally, the hydrology of the Sô River is mainly influenced by two systems: Hlan lake and the Oueme river in its upstream sector and lake Nokoue in its downstream or inferior sector. However, it should be noted that during low water periods, the river plays an important role. On the other hand during the high-water period, there is a dramatic increase in the flow from the lower to the upper course. On the other hand during the high-water period, there is a dramatic increase in the flow from the lower to the upper course. This increase in flow is due to the lateral contributions of the various tributaries leading into the main stream. The hydrological functioning of the Sô River appears to be related to the presence of a source at the Hlan reservoir, which allows a relatively high flow of Sô in the dry season. During the dry season, the Sô river is totally disconnected from the Oueme river, whose low water flow becomes very low. Lake Hlan, upstream of the Sô, which has been recharged during the high period via the dead arm of Oueme (and which also seems to be fed by an underground source) which has become active, is transformed into a source for the Sô River. The flow decreases less and thus brings nearly 90% of the fresh waters of lake Nokoue, the contribution of Oueme corresponding to about 10%. The hydrological conditions of the river are more or less stable and would be favorable to the aquatic fauna of this river.

CONCLUSION

The Sô River has a profile characterized by three distinct sectors: a upper course, an average course and a lower course, all of which have very good cross sections and a good particle size of the substrate. The morphology and hydrological conditions of the Sô River generally show a dynamic equilibrium (good hydro morphological status), favorable to the survival of the aquatic fauna but with a lower course that degrades over the years.

This study constitutes a scientific argument and a decision-making tool from which strong provisions must be made to conserve the ecological conditions offered by the river. This will contribute to the conservation of its ecological continuity and to the improvement of its functioning.

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