Diversity And Spatial Distribution of Benthic Macroinvertebrates of The Sota River in Benin

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Abstract: - The management of running fresh waters requires a good knowledge of their state, their physico-chemical state and biological transformation. Benthic macroinvertebrates are recognized as a biological tool of choice for highlighting disturbances that affect aquatic ecosystems. This study aims to highlight the spatial distribution of macroinvertebrates bio-indicators of the water quality of the Sota river in northern Bénin. The collection of samples was carried out in April during the recession according to the sampling protocol of the Normalized Global Biological Index (IBGN). Thus, a Surber with a unit area of 1/20 m2 and a mesh size of 100 µm was used to harvest macroinvertebrates at four stations: Nassikonsi, Karani, Gbéssé and Koki. Twelve samples were taken per station. These are four samplings of macroinvertebrates in the dominant habitats, four samples taken from marginal habitats and four from complementary habitats. Before sampling, the physico-chemical parameters including temperature, pH, conductivity, transparency, depth and Total Dissolved Solid (TDS) were measured per station. The study identified 10,377 individuals of macroinvertebrates divided into 25 families and 11 orders. This community is made up of 98.17% Insects, 0.83% Shellfish, 0.44% Molluscs, 0.53% Worms and 0.03% Hydracarians. The Diptera order is the most important and constitutes 91.9% of the total richness of macroinvertebrates collected. The chironomidae (78.6%) and ceratopogonidae (13.1%) families are the most frequent and the most abundant. The low values of the Shannon diversity and Piélou equitability indices recorded at the Gbesse and Karani stations reveal that the macroinvertebrate community of these stations is unbalanced and not very diversified. This situation could well be the result of the deterioration of the water quality of the Sota river.

Key Words: ***Inventory, Biodiversity, Aquatic ecosystems, Cotton basin, Sota river, Northeast Bénin.***

I. INTRODUCTION

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Freshwater is essential for all life forms. To this end, it must be present in large quantities and good quality for most human activities and animal life (Menbohan et al., 2011). Activities (industrial, agricultural or urban) can affect water quality and make it unfit for use. Agricultural and urban pollution is the major cause of aquatic ecosystem degradation in rural areas (Leigh et al., 2010, Sass, et al., 2010).

Aquatic ecosystems play essential roles in the conservation and functioning of biodiversity (Aguilar Ibarra, 2004). Qualitative and quantitative monitoring of surface water hydrology is now fundamental (Durozoi, 2009; Gallart et al., 2016; Beaufort et al., 2018). Systems for monitoring their integrity status must be developed using aquatic organisms (Imorou Toko et al., 2012). Biological methods, such as indices based on invertebrate macrofauna, is according to Menbohan et al. (2011) the only valid pathway for the general assessment of the quality of hydrosystems and thus the real effects of pollution. The notion of ecosystem integrity or health requires the simultaneous consideration of chemical, physical and biological parameters (Rioux and Gagnon, 2001).

In this biomonitoring process, benthic macroinvertebrates are considered the most effective (Benetti et al., 2012). They are very important for understanding the structure and functioning of aquatic ecosystems (Camara et al., 2014) and are used as bioindicators to assess the ecological quality of streams (Touzin and Roy, 2008; Gnohossou, 2006). Apart from their role as bioindicators of pollution, benthic macroinvertebrates occupy a very important place in freshwater ecosystems (Moisan, 2010). They are essential in the decomposition of organic matter (Tachet et al., 2010) and are also an important link in aquatic ecosystems, as they are a source of food for many animal species (fish, amphibians, birds, etc.) and therefore can serve as vectors for bioaccumulation of certain contaminants (Savage et al., 2013). From this point of view, studies on the diversity and distribution of the benthic macroinvertebrate community of each aquatic ecosystem is very important. This was therefore the subject of several studies on the inventory of benthic macroinvertebrates of aquatic ecosystems in the cotton basin of northern Benin. These included the work of Aboudou (2010), Imorou Toko et al, (2012), Agblonon-Houelome et al, (2016 and 2017) and Chikou et al, (2018) on the Alibori river and Gouissi et al, (2020) on the Mekrou river.

However, no study has been devoted to the knowledge of macroinvertebrates in the Sota river in Bénin. Data on the inventory and use of macroinvertebrates in the bioassessment of water quality in the Sota river in northern Benin are almost non-existent. Yet, the use of any biological community in water quality conservation and/or monitoring systems requires the characterization of its diversity and structure (Camara et al., 2014).

The purpose of this study is to conduct an inventory of macroinvertebrates in the Sota river, while determining their spatial distribution and the relationships between them and their habitats.

II. Material and methods

2.1 Description of the study environment

The Sota River is located entirely in the cotton basin in northern Bénin. Northern Bénin is the area of greatest agricultural productivity at the national level. Besides the agricultural pressure, the Sota river is also anthropized by fishing and livestock activities. It is a hydrographic network about 250 km long. It is located between 9°54' and 11°95' north latitude and between 2°28' and 3°52' east longitude (Koumassi, 2014). Its area covers 13600 km2, or 11% of that of Bénin. The Sota river is bounded to the northeast by the Niger sub-watershed in Malanville, to the south by the Ouémé watershed, to the southeast by the Za watershed, to the west by the Alibori watershed, and to the east by the Nogourou, Quinté and Ana sub-watersheds (Figure 1).

It covers the communes of Malanville, Ségbana, Kandi and Gogounou in the Alibori department and the communes of Bembèrèkè, Kalalé and Nikki in the Borgou department. The Sota river originates at an altitude of more than 400 m on the eastern flanks of the Kalalé sandstone plateau, which it skirts to the north before heading SSW-NNE on the basement formations. After its source at 90 km, it enters the Cretaceous sandstone formations which it cuts quite deeply and joins the Niger after 250 km of travel, 1 km downstream from Malanville (Le Barbé et al., 1993). This river successively receives the Souamon on its left bank, the Tassiné (102 km long with a surface area of 3031 km2), the Bouli (145 km long and 2380 km2), the lrané (55 km long and 1832 km2), the Gouroukpa and the Sosso waterfall on its right bank. Downstream from Coubéri, the Sota river winds for 15 km through the alluvial deposits of the Niger valley before merging with the Niger 1 km downstream from Malanville. The network is very sparse on the sandstone formations. On the other hand, on the granite and gneissic formations, the hydrographic network is much more important (Vissin, 2007). On its course, the Sota river crosses three forests: the Three River Forests, the Sota Forest and the Goungoun Forest, as well as two main tracks (N'dali-Kalalé and Kandi-Ségbana).

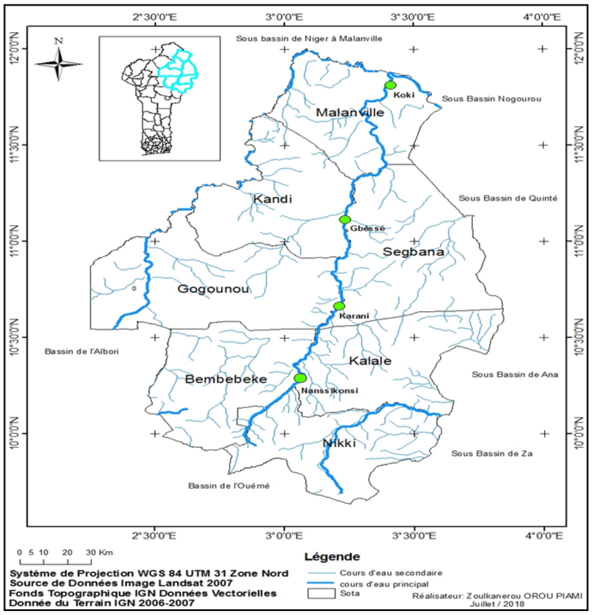

Fig.1. Situation of the Sota watershed

2.2 Selection of Sampling Stations

In order to carry out this study, four stations (Nassikonsi, Karani, Gbéssé and Koki) were surveyed from upstream to downstream on the Sota river (Figure 1). These stations were selected according to the Normalised Global Biological Index (NGBI) standards, i.e. according to depth (less than one meter), current speed (low) and turbidity (low). The length of each station is equal to 10 times the width of the wetted bed.

2.3 Macroinvertebrate Sampling

A single sampling campaign was conducted during this study during the month of April. Macroinvertebrates were sampled using a Surber net with a mesh size of 100 µm and a metal frame with an area of 1/20 of m^2. The sampling consisted of twelve samples on different substrates following the order defined by the Normalised Global Biological Index (NGBI) (Agence de l'eau, 1992). Thus, 12 samples were taken per station: 4 samples on marginal substrates, 4 samples on dominant substrates and finally 4 complementary samples. The habitats or substrates from which these samples were taken were macrophytes, litter, stones (rocks) and sands. Then, the collected macroinvertebrates were preserved with 70% alcohol in boxes labelled by site. These samples were transported to the laboratory for sorting and identification.

2.4 Sorting and identification of macroinvertebrates

In the laboratory, samples were washed and rinsed with plain water to reduce waste from plant debris and mud or sand. Then, the organisms were sorted under a binocular loupe. During this operation, invertebrates were separated according to their morphological appearance and grouped by class, order and family. The taxonomic determination was made up to the family level. The identification of macroinvertebrates was done using the following identification keys: Benthic Macroinvertebrates of New Caledonian Streams (Mary, 2017), Simple Key to the Determination of Freshwater Macroinvertebrates for use by the " Petit gardien des rivières " (Leclercq and Solito de Solis, 2010), Guide d'identification des principaux macroinvertébrés benthiques d'eau douce du Québec (Moisan 2010); Freshwater Invertebrates: Systematics, Biology, Ecology by Tachet et al (2000) and McCafferty's aquatic entomology in 1981. After the determination, the organisms were preserved in 70% alcohol.

2.5 Measurement of the physico-chemical parameters of water

At each station, prior to benthic macroinvertebrate sampling, measurements of physico-chemical parameters (pH, temperature, TDS, conductivity, transparency, wetted bed width and depth) were taken in situ between 8:00 and 12:00. Conductivity, Temperature and TDS were measured using a Conductivimeter (HANNA HI 99300) and pH was measured using a pH meter (HANNA HI 98107). The length and width of the wetted bed were measured with a decameter. The depth of the river water was measured with a graduated ruler while the transparency was measured with a Secchi disk (locally made).

2.6 Data processing and analysis

The analysis of benthic macroinvertebrate data from the Sota river was done using metrics such as taxonomic abundance, taxonomic richness, observation frequency, Shannon diversity index and Piélou index.

Taxonomic abundance = number of individuals for a taxonomic group at a station

Taxonomic richness = number of taxa present in each station

Shannon's diversity index (H') is calculated according to Shannon and Weaver's (1949) formula: $\mathbf{H' = -\sum pi.log2pi}$, with pi the relative abundance of species i in the sample.

Piélou's Equitability Index (E) (Pielou 1969), which is the ratio of true diversity to maximum diversity was calculated by the formula: $\mathbf{E = H'/log\ 2S}$, with S the species richness.

After the normality test of all biological parameters ($p < 0.05$), the variabilities of biological data and physicochemical parameters were evaluated using the Kruskal-Wallis test at the threshold of 5% with the software R3.4.2 (R Core Team 2017). A Principal Component Analysis (PCA) was done using the same software to see the relationships that exist between the physico-chemical parameters, and also between the physico-chemical parameters and the study stations.

The frequency of observation (FO) of the families was determined. It is the ratio between the number of the stations where the family is present by the total number of the stations studied. Three groups were defined (Dajoz, 1985): "very frequent" families have an observation frequency greater than or equal to 50%; "frequent" families have an observation frequency between 25 and 50% and "rare" families have an observation frequency of less than 25%.

The Hierarchical clustering was used to group stations based on the similarity of association of macroinvertebrate families. Also, a Canonical Correspondence Analysis (CCA) was performed using Past software (Hammer et al., 2001), in order to match the data of physico-chemical parameters with those of biological parameters obtained during sampling.

III. Results

3.1 Physico-chemical characteristics of the water of the Sota river basin

The average values of each physico-chemical parameter measured at each station of the Sota river are presented in (Table 1). In general, the physico-chemical parameters such as temperature; pH; conductivity and TDS of the studied waters varied significantly from one station to another ($p < 0.05$) while transparency and depth did not vary ($p > 0.05$). In fact, the average temperature values recorded varied between 30.6°C and 34.2°C (Table 1). The lowest temperature was obtained in the Nassikonsi station (upstream) and the highest temperature was measured in the Koki station (downstream).

The average pH values of the water are between 7.10 and 9.01 over the entire Sota basin. It is noted that the pH of the water of the Sota river increases as one moves from upstream (7.10) to downstream (9.01). The average water transparency of the Sota basin fluctuates between 12.8 cm and 17.5 cm. This transparency decreases progressively as one moves from upstream (Nassikonsi 17.5 cm) to downstream (Koki 12.8 cm).

The average depth values vary between 16.5 cm and 24.1 cm, with the lowest value obtained at the Karani station and the highest value at the Gbéssé station. The average values of the conductivity ranged from 36.16 µS/cm to 48.9 µS/cm, the highest value was obtained in the Gbéssé station and the lowest in Nassikonsi. Similarly, the mean values of TDS have the same trend as those of conductivity at all the stations studied.

The values of the same line (physico-chemical parameter) indicated by different letters (a, b and c), are significantly different at the 5% threshold. While the values of the same line (physico-chemical parameter) indicated by the same letter (a or b or c), have no significant difference at the threshold of 5%. We notice that the indices (a or b or c) of the average values of temperature; pH; conductivity; TDS are different from one station to another, therefore the average values of these parameters have significantly varied from one station to another at the threshold of 5%. As for the indices of the average values of transparency and depth, they are (a) the same at the level of all the study stations, therefore the average values of these parameters did not vary significantly from one station to another at the 5% threshold (Table 1).

Table.1. Water physico-chemical parameters at each station

	Stations				
Physico-chemical parameters	Nassikonsi	Karani	Gbéssé	Koki	*p*-value
Temperature (°C)	$30{,}6±1{,}37^a$	$33{,}5±1.36^b$	$33{,}03 ± 0{,}47^b$	$34{,}2±2{,}09^b$	6.53e-12
pH	$7{,}1±0{,}09^a$	$7{,}28±0{,}09^a$	$7{,}66±0{,}1^b$	$9{,}01±0{,}65^c$	3.062e-13
Transparency (cm)	$17{,}5±4{,}58^a$	$14±6{,}94^a$	$12{,}8±2{,}49^a$	$13{,}1±6{,}92^a$	0.05155
Depth (cm)	$18.4±5{,}71^a$	$16{,}5±7{,}57^a$	$24{,}1±14{,}16^a$	$19{,}1±14{,}77^a$	0.4681
Conductivity (µS/cm)	$36{,}2±1{,}27^a$	$42{,}6±4{,}23^b$	$48{,}9±4{,}01^c$	$38{,}7±2{,}23^a$	3.564e-09
TDS (ppm)	$17{,}8±0{,}62^a$	$21±1{,}91^b$	$24{,}1±1{,}62^c$	$18{,}6±1{,}24^a$	1.711e-10

3.2 Taxonomic diversity of macroinvertebrates in the Sota river

The sampling yielded 10377 individuals of aquatic macroinvertebrates: 2627 individuals at Koki; 3050 at Gbéssé; 2484 at Karani and 2216 at Nassikonsi. This macrofauna belongs to 5 classes (Insects, Mollusks, Crustaceans, Annelids and Hydracarans), 11 orders and 25 families (Table 2). This population is largely dominated by insects which represent 98.17% of the catches. Crustaceans correspond to 0.83%; mollusks (0.44%); worms (0.53%) while hydracarans (0.03%) constitute very marginal communities (Figure 2).

Table.2. List of Macroinvertebrates collected on the Sota River

CLASSES	ORDERS	Families	Koki	Gbesse	Karani	Nassikonsi
CRUSTACEANS	DECAPODES	Astacidae	0	0	0	85
		Potamonidae	1	0	0	0
HYDRACARIANS		HYDRACARIENS	0	0	0	3
INSECTS	DIPTERS	Culicidae	0	0	2	9
		Tabanidae	0	0	4	0
		Ceratopogonidae	1226	85	2	49
		Chironomidae	1210	2875	2352	1718
	COLLEOPTERES	Dytiscidae	4	12	2	2
		Elmidae	33	26	4	18
		Haliplidae	0	0	1	0
	EPHEMEROPTERA	Baetidae	9	2	0	3
		Ephemerellidae	0	0	0	2
	HETEROPTERES	Corixidae	114	14	100	163
		Mesoveliidae	0	0	0	1
		Nepidae	1	0	0	3
	ODONATES	Agriotypidae	2	1	0	0
		Cordulegasteridae	0	0	0	1
		Lestidae	0	1	0	124
		Libelludiae	4	0	2	3
	TRICHOPTERES	Glossosomatidae	0	0	0	1
		Rhyacophilidae	0	2	0	0
MOLLUSCS	BIVALVES	Sphaeriidae	4	6	6	25
		Unionidae	3	1	0	1
WORMS		Nematodes	12	20	8	1
	NEMATODES	Oligochetes	4	5	1	4
		Total	2627	3050	2484	2216

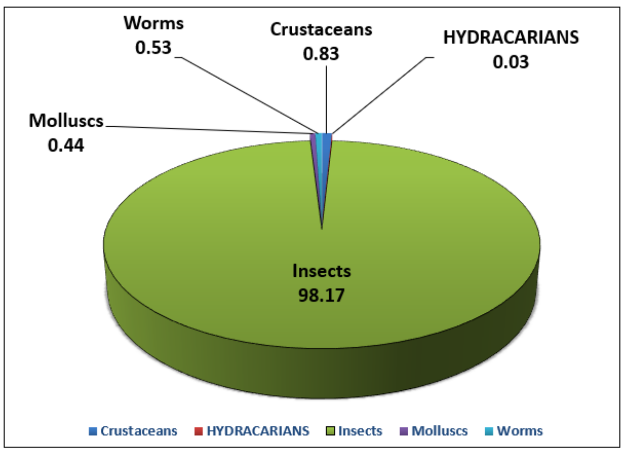

Fig.2. Relative abundances of benthic macrofauna classes in the Sota river

A ranking of orders according to their contribution to taxonomic richness shows that Odonata (4 families) and Diptera (4 families) occupy the first place; Coleoptera and Heteroptera are second with 3 families each; followed by Decapoda, Ephemeroptera and Trichoptera with 2 families each. Hydracarans, Nematodes and Oligochaetes close the round with one family each (Table 3). Regarding the relative abundances, the order Diptera is the best represented, with 91.9%, while the order Trichoptera (0.03%) and Hydracaria (0.03%) are the lowest in terms of total richness (Table 3).

Table.3. Number of individuals and families by order of macroinvertebrates

Orders	Numbers of families	Number of individuals	Abondance relative (%)
Diptera	4	9532	91,9
Bivalves	2	46	0,44
Coleoptera	3	102	0,98
Decapods	2	86	0,83
Ephemeroptera	2	16	0,15
Heteroptera	3	396	3,82
Hydracarans	1	3	0,03
Nematodes	1	41	0,40
Odonata	4	138	1,33
Oligochetes	1	14	0,13
Trichoptera	2	3	0,03

3.3 Class of aquatic insects

Six orders of insects were collected at the four river stations, namely Diptera, Coleoptera, Ephemeroptera, Heteroptera, Odonata and Trichoptera. The latter are present only at the Gbéssé and Nassikonsi stations.

3.3.1 Order of Diptera

The order Diptera represents 67.9% of the insects collected in Koki, 98.1% of those collected in Gbéssé, 95.3% of those in Karani and 84.3% in Nassikonsi. In this order we counted 4 families, namely Ceratopogonidae, Chironomidae, Culicidae, and Tabanidae. The first two families (Ceratopogonidae and Chironomidae) are present in all stations while the last two families (Culicidae and Tabanidae) are only found in the stations of Karani and Nassikonsi. The Chironomidae are the most numerous and represent 49.7% of the Diptera collected in Koki, 97.1% in Gbéssé, 73% in Karani and 97.2% in Nassikonsi.

3.3.2 Order of Coleoptera

The families of Coleoptera present in our samples are Dytiscidae (20 individuals), Elmidae (81 individuals) and Haliplidae (1 individual). The first two families are present in all stations except for the last family (Haliplidae) of the order Coleoptera, which is only present in Karani. In all the taxa collected, 36.3% of the Coleoptera are recorded in Koki; 37.2% in Gbéssé; 6.86% in Karani and 19.6% in Nassikonsi.

3.3.3 Order Ephemeroptera

The two families that make up this order, Beatidae and Ephemerelidae, are sampled in the stations of Nassikonsi, while only Baetidae are present in Koki and Gbéssé. This is the reason why Ephemeroptera are totally absent in Karani. In fact, the Beatidae represent 0.13% of the insects and the Ephemerellidae 0.01%.

3.3.4 Order of Heteroptera

The orders of Heteroptera present in our samples, represent 3.82% of the total abundance. The families sampled in this order are three: Mesoveliidae, Nepidae and Corixidae. Among these families sampled, only the last one mentioned (Corixidae) is present in all 4 stations. Similarly all families are sampled at Nassikonsi. The other families (Mesoveliidae and Nepidae) mentioned were not collected in the other stations (Koki; Gbéssé and Karani). The family Nepidae was represented in low proportions at Koki.

3.3.5 Order Odonata

In the case of the Sota river, four families of Odonata were sampled: Aeschnidae; Cordulegasteridae; Lestidae and Libelludiae. In the case of the latter, the results of the analysis are not statistically significant. The results of the analysis are not statistically significant, but rather they are based on the results of the analysis of the data. In this order, Lestidae are present only at the Nassikonsi station with a maximum of 9% of individuals, at Gbéssé with a minimum of 0.72% of individuals and a total absence at the other stations of Koki and Karani.

3.3.6 The order Trichoptera

In the case of the latter, the number of individuals in the order Trichoptera is the lowest of the orders within the class of insects. In the case of the two families (Glossosomatidae and Rhyacophilidae) of this order, one family (Rhyacophilidae) was sampled in Gbéssé and one (Glossosomatidae) in Nassikonsi.

3.4 Class of Aquatic Worms (Annelids)

The aquatic worms sampled represent 0.53% of the benthic macroinvertebrates collected in the Sota river, of which 0.40% are Nematodes and 0.13% are Oligochaetes. All these two orders (Nematodes and Oligochaetes) that constitute this class are sampled in all stations.

3.5 Class of Molluscs

In this class, two families of the order Bivalves were sampled at the four stations, namely Sphaeriidae and Unionidae. All these two families are present in all four stations except Karani, which does not have Unionidae. After counting, mollusks represent 0.44% of the total macroinvertebrates collected in the Sota River.

3.6 Crustacean class

The Decapoda are the only Crustacea sampled. Two families such as Astacidae and Potamonidae of this order (Decapoda) have been collected. The Potamonidae family was observed only at the Koki station and the Astacidae family was captured only at the Nassikonsi station.

3.7 Spatial variation in macroinvertebrate abundance and taxon richness

The analysis of the taxonomic abundance recorded on the Sota river shows that the distribution of abundance of the stations is quite variable. The lowest abundance was observed at the Nassikonsi station (2216 individuals) in the upstream part of the river and the highest abundance was noted at the Gbéssé station (3050 individuals) downstream (Figure 3).

In addition, the highest taxonomic richness was recorded at the Nassikonsi station (20 families) in the upstream part of the river and the lowest taxonomic richness was observed at the Karani station (12 families) (Figure 3).

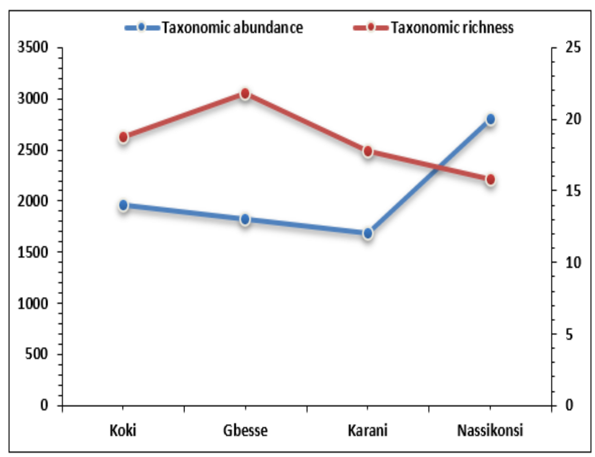

Fig.3. Spatial variation of the abundance and taxonomic richness of macroinvertebrates in Sota river

3.8 Spatial variation of Shannon diversity and Piélou equitability indices

The recorded Shannon diversity index varies between 0.26 bits (at Karani) and 1 bit (at Koki) while that of Piélou's fairness varies between 0.10 bits (at Karani) and 0.38 bits (at Koki) (Figure 4). The high values of these two indices were recorded at the stations of Koki and Nassikonsi while the low values were obtained at the stations of Gbesse and Karani.

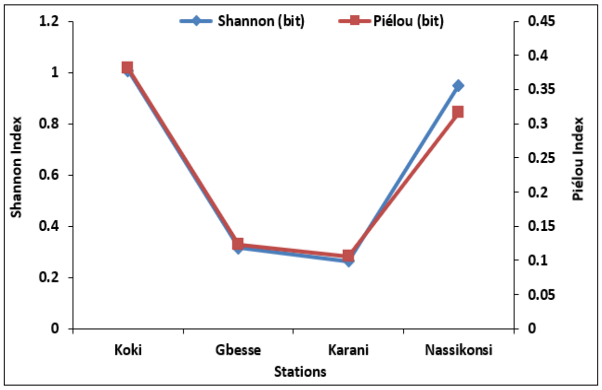

Fig.4. Variation of Shannon and Piélou indices

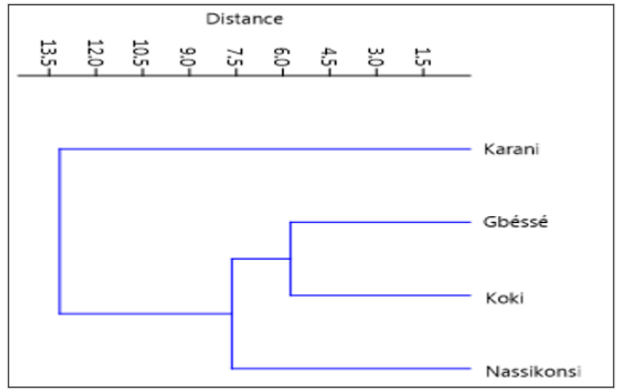

Fig.5. Hierarchical classification of stations

3.9 Frequency of occurrence of macroinvertebrates

Table 4 shows the classification of macroinvertebrate families collected from the Sota river according to their frequency of occurrence. The frequent families (50%>F ≥ 25%) occupy 47.83% of the total richness. While, very frequent families (F ≥ 50%) account for 52.17% of the total richness of the sampled macroinvertebrates (Table 4).

Table.4. Classification of families according to frequency of observation (OF)

Very frequent families (F ≥ 50%)	Frequency of occurrence	Frequent families (50%>F ≥ 25%)	Frequency of occurrence
Agriotypidae	50	Astacidae	25
Baetidae	75	Potamonidae	25
Ceratopogonidae	100	Hydracariens	25
Cordulegasteridae	100	Chironomidae	25
Corixidae	50	Elmidae	25
Culicidae	100	Ephemerellidae	25
Dytiscidae	100	Glossosomatidae	25
Nepidae	50	Haliplidae	25
Sphaeriidae	100	Mesoveliidae	25
Unionidae	75	Rhyacophilidae	25
Nematodes	100	Tabanidae	25
Oligochetes	100		

3.10 Relationship between physico-chemical parameters and macroinvertebrates in the Sota river

An analysis of the hierarchical classification of macroinvertebrate densities in the different study stations shows that the first two axes represent 81% of the information and allow the stations to be divided into three groups (Figure 5): group 1, which includes the Karani station; group 2, which is made up of the Gbéssé and Koki stations; and group 3, characterized by the Nassikonsi station.

In addition, the canonical correspondence analysis (CCA) carried out between the physico-chemical parameters and the densities of macro invertebrates presented three groups: The first group is an intermediate group constituted by the waters of the Karani station, which seems to be related to Haliplidae and Tabanidae. The group 2 is made up of the stations of Gbéssé and Koki, which are positively correlated with axis 1. This station is related to the following parameters: temperature, pH, conductivity, depth and TDS. It seems to be related to the families of Potamonidae, Agriotypidae and Rhyacophilidae. While, group 3 constituted by the Nassikonsi station, which is the source, was negatively correlated with axis 1. The Nassikonsi station has high transparency and is associated with Hydracarans, Culicidae and Ephemerellidae (Figure 6). The CCA reveals that transparency, temperature, conductivity and depth have the greatest influence on the variation of mollusc densities and especially on Hydracarans.

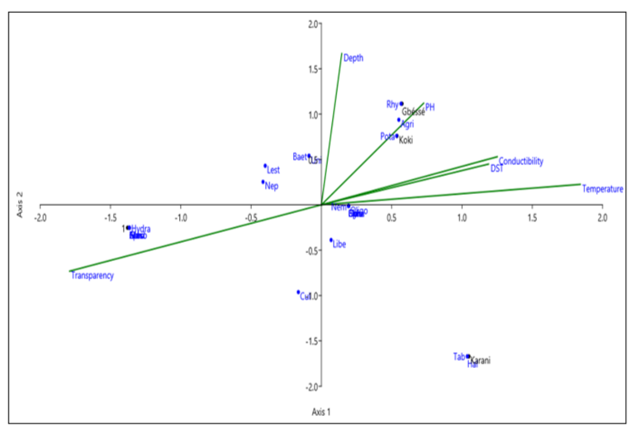

Fig.6. Canonical analysis of the correspondence of benthic macroinvertebrates and physicochemical parameters

Legend: Cul = Culicidae, As = Astacidae, Hy = Hydracariens, Nep = Nepidae, Les = Lestidae, Bae = Baetidae, Uni = Unionidae, Hal = Haliplidae, Tab = Tabanidae, Lib = Libelludiae, Nem = Nematodes, Oli = Oligochetes, Eph = Ephemerellidae, Elm = Elmidae, Pot = Potamonidae, Agri = Agriotypidae, Rhy = Rhyacophilidae; Conductivity; Temperature; pH, Depth and Transparency and DST = Dissolved Solid Total.

IV. Discussion

Physicochemical parameters of Sota river waters varied between stations ($p < 0.05$). The mean values of conductivity (36.2 µS/cm and 48.9 µS/cm) and TDS (17.8 ppm and 24.1 ppm) recorded at our stations are lower than those reported by Agblonon-Houelome et al. (2016) and Diomandé et al., (2009) on the Alibori river in the Bénin Cotton Basin and the Agneby river (Ivory Coast; West Africa), respectively. But these values are below the Normalised Global Biological Index (NGBI) (50 and 1500 µS/cm) (IBGE, 2005). The low average values of measured conductivities reveal the low degrees of overall mineralization of the waters of all study stations (De Nardi et al., 2010). The pH of the Sota river waters ranges from 7.1 to 9 and is slightly above the tolerable limit (6.5 and 8.5) that characterizes waters where life develops optimally (IBGE, 2005). The pH values observed in our study are similar to those (9.01 and 7.4) measured by Balachandran and Ramachandra, (2010) in Bangalore Lake. These authors reveal that the increase in pH may be related to primary productivity where carbonates, sulfates, nitrates and phosphates are converted to hydroxyl. Mean temperatures recorded at all study stations ranged from 30.7 to 34.2°C. Dehedin et al, (2013) had a lower range (12 °C, 18 °C and 24 °C). However, Gouissi et al. (2020) observed similar values on the Mekrou River. The difference in temperature values recorded in the Sota river and the Alibori river could be explained by the heavy deforestation of the Alibori river bank compared to the Sota river. The low water transparency observed in our study is identical to the observation made by Agblonon-Houelome et al (2016) on the Alibori river. This situation could be related to the high amount of suspended matter (mineral or organic matter) (IBGE, 2005; Aboudou, 2010).

Previous studies on aquatic macroinvertebrates by Sanogo et al (2014) in the three water bodies of the Volta basin in Burkina Faso and Diomandé et al (2009) in the Agnéby river in Côte d'Ivoire; report that insects are the most dominant communities. Our results on the Sota river remain consistent with these previous studies. In addition, the number of macroinvertebrate families present in the waters of the Sota river (25 families) are similar to those of the work of Imorou Toko et al (2012) (28 families) obtained on the Alibori river in the same cotton basin of northern Bénin. This observed taxonomic richness (25 families) is very low compared to that (59 families) indicated by studies conducted by Menbohan et al (2010) in the Nga river in Cameroon. The study collected 10377 individuals of benthic macroinvertebrates in the Sota river. This taxonomic abundance is higher than that (132 individuals) observed by (Camara et al., 2014) in the Banco river, but it is much lower than that (39718 individuals) observed by Agblon-Houelome et al (2017). The difference in taxonomic abundance for these different studies is probably due to the sampling method, the types of habitats or substrates surveyed and the equipment used to collect the samples. In all stations studied, the dominant taxa are Diptera (Chironomidae and Ceratopogonidae) and Heteroptera (Corixidae) belonging to the class Insects. The dominance of insects corroborates with the results of previous studies by Sanogo et al, (2014) and those of Alhou et al, (2014). Despite the high insect richness, low abundance of the orders Ephemeroptera and Trichoptera and a total absence of the order Plecoptera was observed. This high richness of other insect groups at the expense of Ephemeroptera and Trichoptera, whose presence is indicative of good water quality, suggests a disturbed environment (Adandedjan 2012; Adandedjan et al, 2012). Similar work carried out in freshwater by Samon et al (2019) and in brackish water by Gnohossou (2006) indicates that the species richness of Ephemeroptera and Plecoptera decreases with the pressure of anthropogenic activities. These taxa, which are known to live in clean, well-oxygenated environments and whose presence in an environment is indicative of good water quality, could not proliferate in an environment that is under the permanent influence of agricultural pressures (Fagrouch et al 2011; Jun et al 2012). The structure of the benthic populations evaluated by means of the Shannon-Weaver diversity and Piélou equitability indices, allowed us to retain that overall, the benthic community of the Sota river is not very diversified and largely unbalanced. Almost all the numbers are concentrated on Chironomidae and Ceratopogonidae, and this could indicate, as reported in several studies, the deterioration of the water quality in this area and consequently the disappearance of several taxa, probably polluo-sensitive (Tachet et al 2000; Piscart 2004) Indeed, the values of the diversity and equitability indices are higher in the stations located downstream and upstream than those located in the middle. Thus, it could be argued that macroinvertebrate communities in the middle of the Sota river basin are poorly diverse and relatively poorly organized. The Koki station located downstream of the Sota river, which presented maximum values of the diversity index (1bit) and equitability (0.38 bits) appears to be the most diverse and stable station. This situation could also be justified by the fact that the Koki station is under less anthropic pressure (absence of agglomeration and cultivation practices), than the other sampling stations. These results are similar to those recorded by Zinsou et al (2016) on the Ouémé delta. After analyzing the abundance and taxonomic richness of the benthic macroinvertebrates collected, the lowest abundance and highest taxonomic richness were observed at the Nassikonsi station (upstream). This high richness could be due to the fact that the Nassikonsi station is located at the source of the Sota river and the lowest abundance could be explained by the beginning of anthropization. Furthermore, except for the Nassikonsi station, the taxonomic richness of the stations increases from upstream to downstream. Thus, from a longitudinal perspective, the pattern of observed richness in the Sota river basin is similar to the predictions of the River Continuum Concept (Vannote et al 1980). The River Continuum Concept predictions, which are not clear, could be justified by the sampling period (dry season) of the study. The receding season when chemicals concentrate and increase their effect on benthic organisms.

Physico-chemical parameters such as temperature, dissolved solids, pH and conductivity (mineralization) of the water influence the distribution of benthic macroinvertebrates (Ward 1992). The assemblage of the downstream stations (Gbéssé and Koki) forming group 2, characterized by a relatively low taxonomic richness and high abundance, could be attributed to the high conductivity and TDS rates. This same result was obtained by Abbou and Fahde (2017) and Oualad et al (2009). According to Oualad et al, (2009), high mineralization leads to a reduction of taxonomic richness in a benthic stand. Indeed, the high values of conductivity led to the total absence of Plecoptera, the disappearance of some Trichoptera and Ephemeroptera. Consequently, the taxonomic richness of the benthic communities was impoverished. Group 3 is constituted by the Nassikonsi station, which is the source, is characterized by a high water transparency, a low temperature and a low pH. This station is the only one where two families (Ephemerellidae and Baetidae) were observed. These observations corroborate with the results of Touzin and Roy (2008). According to these authors, Plecoptera, Trichoptera and Ephemeroptera are the most sensitive groups to pollutants and require well oxygenated and less polluted water at a cool temperature.

V. Conclusion

The macroinvertebrate community inventoried in this study includes 10377 individuals divided into 5 classes, 25 families and 11 orders. The results obtained reveal that the orders Diptera and Heteroptera are the most important. The other faunal groups constitute only a small fraction of the collected fauna. The families Chironomidae and Ceratopogonidae are the most frequent and abundant. Their preponderance indicates the poor water quality of the Sota river. The analysis of the structure of the benthic fauna of the different study stations reveals a poorly diversified and largely unbalanced population. Transparency, temperature and pH are the environmental parameters that discriminated the distribution of organisms in the Sota river basin. This study deserves to be deepened in order to evaluate the ecological quality and to define biological indices of quality monitoring in the future.

References

[1]. Abbou, F. & Fahde, A. (2017). Structure et diversité taxonomique des peuplements de macroinvertébrés benthiques du réseau hydrographique du bassin du Sebou (Maroc). International Journal of Biological and Chemical Sciences. 11, pp. 1785–1806.

[2]. Aboudou, E. F. (2010). Caractérisation de la diversité et de la structure des macroinvertébrés benthiques du bassin cotonnier Béninois : Banikoara, Kandi, Gogounou. Thèse d'Ingénieur Agronome, Université de Parakou, Parakou, Bénin, 94 p.

[3]. Adandedjan, D. (2012). Diversité et déterminisme des peuplements de macroinvertébrés benthiques de deux lagunes du Sud- Bénin : la Lagune de Porto-Novo et la Lagune Côtière. (Thèse de doctorat). Université d'Abomey-Calavi-Bénin, Bénin. 261 p.

[4]. Adandédjan, D., Lalèyè, P., Gourène, G. (2012). Macroinvertebrates communities of a coastal lagoon in southern Benin, West Africa. International Journal of Biological and Chemical Sciences. 6, pp. 2131 - 2138.

[5]. Agblonon-Houelome, T. M. A. Adandedjan, D. Chikou, A. Toko Imorou,. I. Bonou, C. Youssao, I & Laleye, P. (2016). Evaluation de la qualité des eaux des ruisseaux du cours moyen de la rivière Alibori par l'étude des macroinvertébrés benthiques dans le bassin cotonnier du Bénin (Afrique de l'Ouest). International Journal of Biological and Chemical Sciences. 10, pp. 2461–2476.

[6]. Agblonon-Houelome, T. M. A. Adandedjan, D. Chikou, A. Toko, I. I. Koudenoukpo, C. Z. Youssao, I. & Laleye, P. (2017). Inventaire et caractéristiques faunistiques des macroinvertébrés de la rivière Alibori dans le bassin

cotonnier du Bénin. International Journal of Innovation and Applied Studies. 21, pp. 433–448.

[7]. Agence de l'eau (1992). Indice Biologique Global Normalise (I.B.G.N NF - T 90 - 350): Guide technique.

[8]. Aguilar Ibarra, A. (2004). Les peuplements de poissons comme outil pour la gestion de la qualité environnementale du réseau hydrographique de la Garonne (PhD Thesis). Institut National Polytechnique de Toulouse, 147 p.

[9]. Alhou, B., Issiaka, Y., Awaiss, A. & Micha, J.-C. (2014). Premier inventaire des macro-invertébrés du fleuve Niger à Niamey comme bioindicateurs de la pollution urbaine et industrielle. Hydroécologie Appliquée. 18, pp. 139–163.

[10]. Balachandran, C., Ramachandra, T., 2010. Aquatic macroinvertebrate diversity and water quality of bangalore lakes. Wetlands: Biodiversity and Climate Change. Bangalore: Energy and Wetland Research Group, Centre for Ecological Sciences, Indian Institute of Science, Bangalore-560 012. 18p.

[11]. Beaufort, A., Lamouroux, N., Pella, H., Datry, T. & Sauquet, E. (2018). Extrapolating regional probability of drying of headwater streams using discrete observations and gauging networks. Hydrology and Earth System Sciences. 22, pp. 3033–3051.

[12]. Benetti, C. J., Pérez-Bilbao, A., Garrido, J. (2012). Macroinvertebrates as Indicators of Water Quality in Running Waters: 10 Years of Research in Rivers with Different Degrees of Anthropogenic Impacts, Ecological Water Quality - Water Treatment and Reuse, Dr. Voudouris (Ed.).

[13]. Camara, A. I., Diomande, D. & Gourene, G. (2014). Impact des eaux usées et de ruissellement sur la biodiversité des macroinvertébrés de la rivière Banco (Parc National du Banco; Côte d'Ivoire). Sciences de la vie, de la terre et agronomie. 2, pp. 58-68.

[14]. Chikou, A. Agblonon-Houelome, T. M. Adandedjan, D. Imorou Toko, I. Karim, I. Y. A. & Laleye, A. P. (2018). Structural organization of the macroinvertebrates communities of the Alibori River during the rainy season (Northern Benin). International Journal of Fisheries and Aquatic Studies. 6, pp. 285–291.

[15]. Dajoz, R. (1985). Précis d'Ecologie. Edition. Dunod: Paris. 615p.

[16]. De Nardi, F., Puaud, C., Lodé, T., Lecorff, J., Parinet, B. & Pontié, M. (2010). Diagnostic préliminaire et perspectives d'élimination du phosphore (P) en excès dans le lac de Ribou (Cholet, Maine-et-Loire, France). Revue des sciences de l'eau/Journal of Water Science. 23, pp. 159–171.

[17]. Dehedin, A., Piscart, C., & Marmonier, P. (2013). Seasonal variations of the effect of temperature on lethal and sublethal toxicities of ammonia for three common freshwater shredders. Chemosphere. 90, pp. 1016–1022.

[18]. Diomandé, D., Bony, K. Y., Edia, O. E., Konan, K. F. & Gourène, G. (2009). Diversité des Macroinvertébrés benthiques de la rivière Agnéby (Côte d'Ivoire; Afrique de l'ouest). European Journal of Scientific Research. 35, pp. 368–377.

[19]. Durozoi, B., Baudoin, J-M. & Tomanova, S. (2009). Un outil national d'observation de l'hydrologie permettrait-il une meilleure comprehension du fonctionnement des ecosystemes aquatiques et la gestion efficace des periodes de crise?, Colloque 193 SHF : «Etiages, Sécheresses, Canicules rares et leurs impacts sur les usages de l'eau», Lyon, pp. 7-8.

[20]. Farouch, A., Berrahou, A. & El Halouani, H. (2011). Impact d'un effluent urbain de la ville de Taourirt sur la structure des communautés de macroinvertébrés de l'oued Za (Maroc oriental). Revue des sciences de l'eau/Journal of Water Science. 24, pp. 87–101.

[21]. Gallart, F. Llorens P. Latron J. Cid N. Rieradevall M. & Prat N. (2016). Validating alternative methodologies to estimate the regime of temporary rivers when flow data are unavailable. Science of the Total Environment. 565, pp. 1001–1010.

[22]. Gnohossou, P. (2006). La faune benthique d'une lagune ouest Africaine (le lac Nokoue au Bénin), diversite, abondance, variations temporelles et spatiales, place dans la chaine trophique. Institut National Polytechnique de Toulouse. 185 p.

[23]. Gouissi, F. M., Abahi, K. S., Adje D. D., Gbenou, W. A. & Gnohossou, M. P. (2020). Macroinvertebrate communities of Mékrou River in Benin and their relationship with environmental factors. J. Entomol. Zool. Stud. 8, pp. 654–661.

[24]. Hammer, Ø., Harper, D. A. & Ryan, P. D. (2001). PAST: Paleontological statistics software package for education and data analysis. Palaeontologia electronica 4, 9p. University of Oslo, Sars gate1, 0562 Oslo, Norway.

[25]. IBGE (2005). IBGE (Institut Bruxellois pour la Gestion de l'Environnement), Qualité physico-chimique et chimique des eaux de surface: cadre général. 16 p.

[26]. Imorou Toko, I. Atttakpa, Y. Gnohossou, P. & Aboudou, E. F. (2012). Biodiversite et structure des macroinvertebres benthiques du bassin cotonnier beninois. Annales des Sciences Agronomiques. 16, pp. 197–214.

[27]. Jun, Y-C., Won, D-H., Lee, S-H., Kong, D-S. & Hwang, S-J. (2012). A multimetric benthic macroinvertebrate index for the assessment of stream biotic integrity in Korea. International journal of environmental research and public health. 9, pp. 3599–3628.

[28]. Koumassi, H. D. (2014). Risques hydroclimatiques et vulnérabilités des écosystèmes dans le bassin versant de la Sota à l'exutoire de Couberi (Thèse de doctorat). Université d'Abomey- Calavi, Bénin. 246p.

[29]. Le Barbé, L., Alé, G., Millet, B., Texier, H. & Borel, Y. (1993). Les ressources en eaux superficielles de la République du Bénin. Monographies hydrologiques ORSTOM. 543p.

[30]. Leclercq, L. & Solito de Solis, M-M. (2010). Clé simple de détermination des macroinvertébrés d'eau douce à l'usage du « petit gardien des rivières », 2010th ed. Université de Liège.

[31]. Leigh, C., Burford, M. A., Roberts, D. T. & Udy, J. W. (2010). Predicting the vulnerability of reservoirs to poor water quality and cyanobacterial blooms. Water Research. 44, pp. 4487-4496.

[32]. Mary, N. (2017). Les macroinvertébrés benthiques des cours d'eau de la Nouvelle-Calédonie. Guide d'identification. Version révisée 2017, DAVAR Nouvelle-Calédonie. Ed. OEIL, CNRT. 182 p.

[33]. McCafferty, P. W. (1981). Aquatic entomology. The fisherman's and ecologists'Illustrated. Guide to Insects and their relatives, Jones and Bartlett publishers Bostom. London. 448 p.

[34]. Menbohan, F. Zebaze, T. S. H. Nyamsi, T. N. L. & Njiné, T. (2010). Macroinvertébrés Benthiques du cours d'eau Nga: Essai de Caractérisation d'un Référentiel par des Analyses Biologiques. European Journal of Scientific Research 43: 96–106.

[35]. Menbohan, S. F. Togouet, S. Z. Tchatcho, N. N. & Njine, T. (2011). Evolution spatiale de la diversité des peuplements de macroinvertébrés benthiques dans un cours d'eau anthropisé en milieu tropical (Cameroun). European Journal of Scientific Research. 55, pp. 291–300.

[36]. Moisan, J. (2010). Guide d'identification des principaux macroinvertébrés benthiques d'eau douce du Québec, 2010: surveillance volontaire des cours d'eau peu profonds. Développement durable, environnement et parcs Québec.

[37]. Oualad, M. N. Kamal, T. & Stitou, J. (2009). Evaluation de la qualité des eaux dans les systèmes fluviaux du Rif (cas de la rivière Martil) et étude de la biodiversité des communautés de macroinvertébrés. Segundo congreso internacional sobre geologia y mineria en la ordenación del territorio y en el desarrollo. Utrillas. pp. 95- 114.

[38]. Pielou E. C. (1969). An introduction to mathematical ecology. Wiley Interscience, New York. VIII + 286 S., 32 Abb., Preis 140 s.

[39]. Piscart, C. (2004). Rôle de la salinité dans la dynamique et la régulation de la biodiversité des communautés de macroinvertébrés dulçaquicoles. Thèse de Doctorat, L'Université de METZ, 231p. France 232 p.

[40]. R Core Team (2017). R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria.

[41]. Rioux, S. & Gagnon, F. (2001): Développement d'un indice biotique pour évaluer l'état de santé des petits cours d'eau en milieu agricole dans le bas Saint – Laurent. FAPAQ, Direction de l'aménagement de la faune de la région du bas Saint Laurent. Document du Bape Bio. 78, 93 p.

[42]. Samon, O. S. Gouissi, F. M. Adje, D. D. Abahi, K. S. Tchaou, C. M. Okoya, J. G. A. Orou Piami, Z. Gnohossou, M. P. Omoniyi, G. & Piscart, C. (2019). Abundance and distribution of macroinvertebrates of the Affon River in Bénin. Open Journal of Marine Science. 9, pp. 173–187.

[43]. Sanogo, S. Kabre, J. A. T. & Cecchi, P. (2014). Inventaire et distribution spatio-temporelle des macroinvertébrés bioindicateurs de trois plans d'eau du bassin de la Volta au Burkina Faso. International Journal of Biological and Chemical Sciences. 8, pp. 1005–1029.

[44]. Sass, L. L. Bozek, M. A. Hauxwell, J.A. Wagner, K. & Knight, S. (2010). Response of aquatic macrophytes to human land use perturbations in the watersheds of Wisconsin lakes, U.S.A. Aquatic Botany. 93, pp. 1-8.

[45]. Savage, C. Armellin, A. & Jean, M. (2013). Suivi de l'état du Saint-Laurent. Les communautés de macro-invertébrés benthiques.

[46]. Shannon, C. E. & Weaver, W. (1949). The mathematical theory of communication university of Illinois press Urbana 131p.

[47]. Tachet, H. Richoux, P. Bournaud, M. & Usseglio-Polatera, P. (2000). Invertébrés d'eau douce : systématique, biologie, écologie. CNRS Editions 588 p.

[48]. Touzin, D. & Roy, M. (2008). Utilisation des macroinvertébrés benthiques pour évaluer la dégradation de la qualité de l'eau des rivières au Québec. Faculté des sciences de l'agriculture et de l'alimentation Université Laval. Quebec, Canada. 40p.

[49]. Vannote, R. L. Minshall, G. W. Cummins, K. W. Sedell, J. R. & Cushing, C. E. (1980). The river continuum concept. Can. J. Fish. Aquat. Sci. 37, pp. 130–137.

[50]. Vissin, E. (2007). Impact de la variabilité climatique et de la dynamique des états de surface sur les écoulements du bassin béninois du fleuve Niger (PhD Thesis). Université de Bourgogne. 311 p.

[51]. Ward, J. V. (1992). Aquatic Insect Ecology.1. Biology and Habitat. John Wiley & Sons, Inc., New York, 438 p.

[52]. Zinsou, L. H. Gnohossou, P. Adandedjan, D. & Laleye, P. (2016). Profil de distribution des macroinvertébrés benthiques du delta de l'Ouémé à partir du Self Organizing Map (SOM). 12,1, pp. 224-236.