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Impact of deforestation on the aquatic macroinvertebrate community and the ecological quality of Mé River (South-East, Côte d'Ivoire)

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ABSTRACT

Forests have become one of the most altered biomes. This study aimed to assess the impact of deforestation on the ecological quality of Mé River. Macroinvertebrate were collected at 9 sites in Mé watershed using a hand net and a Van Veen grab, after measuring abiotic parameters. QGIS software was used to determine the proprotion of different land use class. Hierarchical Cluster Analysis (HCA) has grouped the sites into groups. To assess the diversity of macroinvertebrates in these groups, Piélou's evenness, Shannon-Weaver index and Rarefied richness were used. Water quality index (WQI), EPT and Chironomidae indices were used to describe the ecological quality. Deforestation and the ecological quality have been linked by using Focused Principal Component Analysis. S1, S6, S7, S8 and S9 characterized by a high proportion of bare ground had been classified in group 1 (GI) by the HCA. S2, S3, S4 and S5 with high proportion of wooded crops had been classified in group 2(GII). Phosphorus, pH, nitrites, and ammonium varied significantly between GI and GII. High nutrient, nitrates (22.7 mg/L), ammonium (1.92 mg/L), phosphorus (0.55 mg/L) were recorded in GII. Water from S2 and S5 turned out to be of poor quality. WQI was strongly correlated with the dense forest Class. A total of 187 macroinvertebrate taxa gathered in the sites. GII was most diversified. Deforestation has led to decline species diversity. Mé River has an acceptable ecological quality.

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INTRODUCTION

Forests are recognized as high priority natural habitats (Fermond *et al.,* 2021). They are home to an abundance of biodiversity and provide a wide range of ecosystem services (Mori *et al.,* 2017). Tropical forests in particular are considered to be centers of biodiversity with a high level of endemism for many species (Hoekstra *et al.,* 2005; Myers *et al.,* 2000). However, these forests have become one of the most altered biomes (Laurance *et al.,* 2014a). Human pressures linked to agricultural expansion and increasing urbanization are leading to a drastic reduction in forest cover (Laurance *et al.,* 2014b). These practices also lead to ecological changes in natural environments such as aquatic ecosystems (FAO, 2020). Deforestation affects the hydrological regime of stream by increasing sediment level (Zhao *et al.*, 2022). It also encourages bank erosion, which can increase nutrient loads. Fluctuations in resource availability have an impact on aquatic habitats (Webster *et al.,* 1992; Gresens *et al.,* 2007), and for instance could disrupt the dynamics and the diversity of aquatic entomofauna (Monteiro-junior *et al.*, 2013). Spatial and temporal changes in habitats provide a shifting mosaic of abiotic and biotic conditions that play a major role in organizing stream communities. Abiotic factors, in particular those related to disturbance (Poff, 1992) and/or habitat heterogeneity that buffers against disturbances (Robinson and Minshall, 1998), clearly determine the composition of invertebrate communities. The effects of habitat modification on aquatic biodiversity such as macroinvertebrate communities in stream are well documented. Indeed, they are essential to the trophic guild (Callisto *et al.*, 2002), the nutrients cycle, and are also used as a bioindicators due to their weak mobility which is an asset to integrate events that occurred during longer or shorter period (Tachet *et al.*, 2010). In Côte d'Ivoire the watershed of Mé River is heavily impacted by deforestation (Ouattara *et al.*, 2023). Yet, this river is potential source of drinking water for population. Studies have been carried on macroinvertebrate communities in tropical region. In Côte d'Ivoire, there have been focused on macrofauna in relation to the ecological quality of lotic waters (Edia *et al.*, 2008, 2013; Camara *et al.*, 2020). Impact of deforestation on water ecological quality are rare. Reference Nina *et al.* (2025) studied the effect of deforestation on the ecological quality of some rivers based on macroinvertebrates in western Côte d'Ivoire. In addition to that, no impact assessment study of deforestation was conducted on the ecological quality of Mé River base on macroinvertebrates. However, it is evident that deforestation influences negatively structure, diversity and functional organizations of aquatic macroinvertebrates (Bojsen and Jacobsen, 2003).

Furthermore, the only study focusing on macroinvertebrates in the Mé watershed, is that by N'ZI *et al.,* 2003, which examined shrimp diversity and its relation to environmental gradients. To remedy this, the aims of this study were to investigate the effect of deforestation on the taxonomic structure of macroinvertebrate then to indicate the bioecological quality of this river.

MATERIALS AND METHODS

Study area and sampling sites

The study was conducted from december 2020 to january 2022 in Mé whatershed. This watershed is located between 5° 30 and 6°20 north and between 3°30 and 4° 10 west in Côte d'Ivoire (Fig. 1). With 140 km of length, Mé River drains an approximate area of about 4140 km². Wood logging and crop farming are the major occupations of local people in the area. So the occurrence of small primary forest, secondary forest and deforested areas is typical for this area. But traditional gold mining is increasing (Table 1).

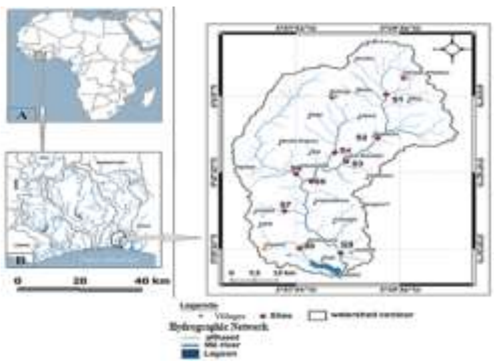

Fig 1. River Mé watershed localization

Table 1. Coordinates, level of anthropogenic activities and substrate characteristics at each sampled point

Sites	Geographicals coordinates			Human activities	Substrates characteristics (%)				
	Longitude (w)	Latitude (N)	Location		Plants debris	Gravel	Coarse sand	Fine sand	Clay and silt
S1	3°42'51"	6°10'6"	Ahuikoi	Watering place, farming	8.59	0	13.74	72.85	4.81
S2	3°43'28"	5°55'57"	Basadzin	Gold panning	28	0	5.3	55	11.7
S3	3°49'3"	5°50'23"	Lobo-Akoudzin	Fishing, farming	8	50.67	31.04	10.29	0
S4	3°51'3"	5°52'27"	Lobo-ope	Fishing, farming	10	35.2	30.47	18.12	6.2
S5	3°55'10"	5°45'37"	yakassemé	Dredging,farming	5	60.88	25.79	8.32	0
S6	3°57'50"	5°47'21"	Mafou	Dredging, drinking	31.95	0.34	9.86	56.8	1.05
S7	3°59'53"	5°40'44"	Abbè	Dredging	7	15	30.5	40.5	7
S8	3°57'17"	5°29'33"	Ahoue	Watering place	26	0.3	2.92	30.55	40.23
S9	3°50'2"	5°28'26"	Irho	Fishing	40.14	0	0	19.17	40.69

Table 2. Water quality index (WQI) range, status, and possible usage of water (Brown, 1972)

WA WQI value	Status	Possible usages
0-25	Excellent	Drinking, Irrigation and Industrial purpose
26-50	Good	Domestique, Irrigation and Industrial purpose
51-75	Poor	Irrigation and Industrial purpose
76-100	Very poor	Industrial

Four climatic seasons features the area: two rainy seasons and two dry seasons. The dry season spans from October to March, while the rainy season is between March and September. Nine (09) sites in the watershed were selected for the present study (see for geographical location of the nine sites sampled).

Remote sensing land-use/cover

In this study, two sentinel-2 images from the European Space Agency website have been used to map the land use/ cover. These data are from pre-processing level 1C, acquired on the copernicus website (https://dataspace.copernicus.eu). Alos palsar 12.5 m image from website https://asf.alaska.edu/datasets/daac/alos-palsar, has been used to extract the watershed and hydrographic network of Mé River. Land use analysis process was conducted using QGIS 3.36.1. To evaluate land use/cover around the sites, Tabulate Area function ($area) in QGIS was used to calculate (in km²) and converted into percentage of land cover/use within a 500 m buffer around each sampling site to illustrate change in natural habitat structure of the river (Wang *et al.*, 2018).

Physicochemical parameter sampling

Sampling was carried out from December 2020 to January 2022. Physicochemical parameters were measured to assess the water quality. At each sampling point before macroinvertebrate sampling, pH, temperature, conductivity, dissolved oxygen, the total dissolved solids (TDS) were determined at the same sampling point with a portable multi-parameter HANNA (991001, 9146). Water was also collected with bottle of 1L at each site. Samples were transported to the laboratory under cool conditions and stored at 4°C for nutrients (ammonium, nitrites, nitrates, phosphorus) analyses. Nutrient dosages were done by using spectrophotometer and were carried out according to the protocol as defined by Rodier *et al.* (2009).

In addition, water quality index has been evaluated based on physico-chemical parameters. This is the Weight arithmetic water index (WAWQI). This method classified the water quality according to the degree of purity (Table 2) using some of water quality parameters such as temperature, pH, turbidity, fecal coliform, dissolved oxygen, biochemical oxygen demand, total phosphates, nitrates and total solids (Roşu *et al.*, 2013).

In this study we used pH, Dissolved oxygen, Temperature, Conductivity, Total dissolved solids, Nitrate, Ammonium, Nitrite, Phosphorus to calculate the water quality index.

The water quality index (WQI) verified:

$$WQI = \frac{\sum_{i=1}^{n} W_i Q_i}{\sum_{1}^{n} W_i}$$

Where, Q_i=sub-index for i^{th} water quality parameter;

$$Qi = \frac{100(V_i - V_0)}{S_i - V_0}$$

V_i observed value, V_o =ideal value (V_o=0), except pH (V_o=7) and Dissolved oxygen (V_o=14.6 mg/L)

S_i is the standard allowable value for the i^{th} parameter.

Wi = weight associated with i^{th} water quality parameter;

W_i=k/S_i Here, $k = \frac{1}{\Sigma(\frac{1}{S_i})}$

k= proportionality constant, n = number of water quality parameters

For the standard value of each parameter, we have considered the recommendations of the World Health

Macroinvertebrate sampling

We used at all sampling point a multi-habitat sampling norm (Barbour *et al.*, 1999). In the field, we employed D-frame kick net (with a size of 30 × 30 cm and a mesh size of 250 µm) and Van Veen grab of 0.05 m^2 internal area was used. The samples were sieved in field through a 1 mm mesh and the material retained on this mesh was preserved in 70 % alcohol. In the laboratory, samples were washed using 1 mm sieves. Macroinvertebrates were separated from organic matter. By using stereo microscope (Olympus SZ 40), the collected macroinvertebrate specimens were counted and identified to the lowest taxonomic level possible, means of keys in Dejoux *et al.* (1981), Day *et al.* (2001a, 2001b), De Moor *et al.* (2003a, 2003b), Stals *et al.* (2008), for Insecta, Tachet *et al.* (2010) for other Insecta, Acheata and Oligocheata, Brown (1994) for Gasteropoda and FAO (2016) for Crustacea.

Analysis of structure of macroinvertebrate

To describe the ecological condition of river in response to deforestation, the structure of macroinvertebrate communities was assessed using Shannon-Weaver diversity index (H') (Shannon and Weaver (1963), Clarke and Warwick (2001)) and Pielou Evenness Index (J') (Pielou, E.C. (1966)). Taxonomic richness was rarefied to avoid any bias at related to differences in abundance (Edia *et al.*, 2016).

Rarefaction used the lowest observed abundance across all sites as the standard and was carried out using the "vegan" package in R (Oksanen *et al.*, 2013).

Water quality assessment

Macroinvertebrate metrics were used to assess biological water quality by using the four following biological indices:

$$\left(\frac{\sum \text{Chironomidae}}{\sum \text{all.taxa}}\right)*100$$

$$\left(\frac{\sum \text{EPT}}{\sum \text{Chironomidae} + \sum \text{EPT}}\right)*100$$

$$\left(\frac{\sum \text{EPT}}{\sum \text{all.taxa}}\right)*100$$

$$\left(\frac{\sum \text{Baetidae}}{\sum \text{Ephemeroptera}}\right)*100$$

Chironomidae index should increase depending on the level of environmental degradation. The EPT (Ephemeroptera, Plecotera and Trichoptera) divided by the sum of Chironomidae added the sum of EPT ratio should decrease as disturbances increase. The percentage Ephemeroptera, Plecotera and Trichoptera (EPT) should decrease in the presence of disturbances and the percentage of Baetidae should increase as disturbances increase. EPT are sensitive to water quality impairment and environmental stress (Akamagwuna *et al.*, 2019).

Statistical analysis

The sampling sites were grouped based on the six land use classes (Crops, water, Clear Forest, Dense Forest, Habitat and road, Bare ground) using hierarchical cluster analysis (HCA); ward's linkage method according the degree of deforestation. Data distribution was assessed using Shapiro's normality test. Since most variables were not normally distributed, the Mann-Whitney non-parametric test was applied to examine differences in abiotic and biotic parameters among the site groups. A significance level of $p< 0.05$ was considered.

Relationships between these indices and the lands use /cover were performed using Focused Principal Component Analysis (FPCA). FPCA presents correlations in graphic format as concentric circles, those of smaller radius representing stronger correlations. The center of these circles (target) contains the variable of interest, which directs the analysis. Negative and positive correlations are differentiated in the graph by use of different colors. The interpretation of points in an FPCA graph is as follows: The closer the point is to the center, the closer to 1 (or -1) is the correlation between the index and the variable of interest; Two points close to one another indicate a strong positive correlation between the index which they represent; Two diametrically opposed points indicate a strong negative correlation between the index which they represent; Two points placed at a similar distance from the origin, parallel to one of the axes, indicate absence of correlation between the index which they represent; The dashed circle delimits statistical significance at the 5% level (Canuto, 2010).

Statistical tests were considered significant at $p < 0.05$, while p value between 0.05 and 0.1 were considered to be marginally significant. All statistical analyses were performed using R software, version 4.6.0 (Team R core, 2023).

RESULTS

Land use/Cover map

The land cover/use map for each the sampling site area in the Mé watershed in 2022 is shown in Fig. 2. Six land use categories have been defined (Table 3). The crops class highest value (0.49539) was obtained at the site S3 and the lowest (0.05373) at the site S1. The value of water class (0.23543) was relatively high at the site S8 and relatively lower at the site S2 (0.00788). The clear Forest class, on the other hand, showed a relatively high value (0.16612) at the site S1 and the lowest (0.00431) at the site S9. For the dense Forest class, the highest value (0.34202) was obtained at the site S2, this class was absent at site S9. Habitation and road class showed a relatively higher value (0.18035) at site S8. This class was absent at site S2. The class of Bare ground varied from (0.26728) at site S2 to (0.61012) at the site S7.

Table 3. Frequency of land use /cover classes around the sampling sites in Me River watershed in 2022

Sites	Land use / Cover classes					
	HR	Wa	FD	CU	FC	BG
S1	0.05908	0.05057	0.17804	0.05373	0.16612	0.49246
S2	0.00000	0.00788	0.34202	0.26069	0.12212	0.26728
S3	0.02611	0.03331	0.01893	0.49539	0.05090	0.37536
S4	0.04089	0.00823	0.13742	0.44517	0.09303	0.27527
S5	0.00566	0.03639	0.12654	0.40686	0.07732	0.34724
S6	0.06280	0.08504	0.01331	0.16710	0.07715	0.59461
S7	0.03196	0.11667	0.01143	0.07631	0.15351	0.61012
S8	0.18035	0.23543	0.00056	0.09962	0.03069	0.45334
S9	0.03304	0.19748	0.00000	0.29294	0.00431	0.47223

CU=Crops, Wa= water, FC= Clear Forest, FD=Dense forest, HR=Habitat and road, BG= Bare ground

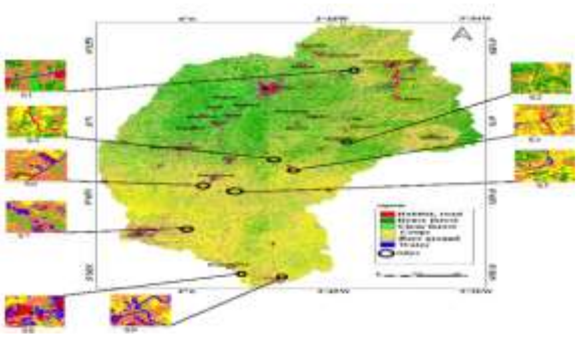

Fig. 2. Land cover/use maps for each the sampling site area in the Mé watershed in 2022; S1, S2, S3, S4, S5, S6, S7, S8, S9 indicate the sampling sites

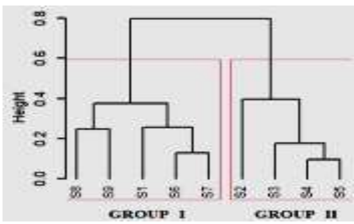

Fig 3. Hierarchical cluster analysis (HCA) of sites according to their affinity based on land cover/use classes in 2022

HCA was used to group sites according to their affinity based on land cover/use classes (Fig. 3). Two group was distinguished, the group I (GI) consists of five sites (S1, S6, S7, S8, S9) characterized by a high proportion of bare ground, water, habitations and road. Each of these sites has a percentage of bare ground exceeding 45% of the total area. GI was therefore considered to be a bare ground area. Group II (GII) included sites S2, S3, S4 and S5. These are characterized by high proportion of wooded crops and dense forest. Each of these sites has wooded crops cover of more than 40% of its total area. GII was therefore considered to be a forest area.

Abiotic parameters

The variation of abiotic parameters (pH, Temperature, Dissolved oxygen, Conductivity, Nitrites, Nitrates, Ammonium, Phosphorus, Total dissolved solid) among the groups of sampled sites are shown in Fig. 4.

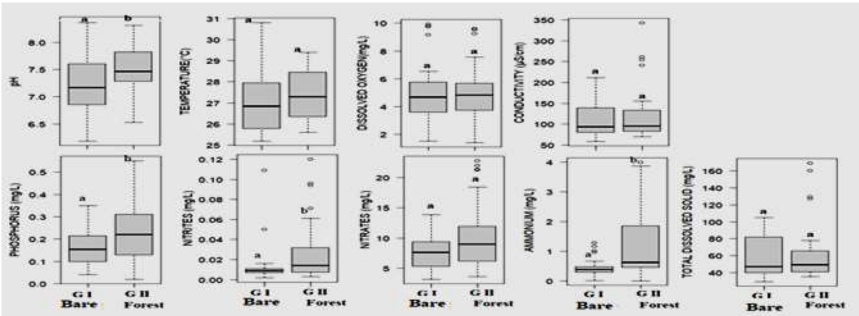

Fig. 4. Spatial variation of abiotic parameters among the group of sampled sites obtained from HCA (GI= Group I, GII= Group II) in 2022; for each parameter, boxplot with common letter (a) do not differ significantly (Mann-Whitney, *p*-value > 0.05)

Table 4. Taxonomic list and occurencies of macroinvertebrates recorded at each sampling point in Mé River in 2022

Class	Taxa	Sites								
		S1	S2	S3	S4	S5	S6	S7	S8	S9
Order										
Family										
Arachnida										
Areneae										
Pisauridae	*Thalassius* sp.			*	*	*	**		*	
Tetragnathidae	*Tetragnatha* sp.				*	**	*		*	*
Bivalva										
Unionoida										
Unionidae	*Coelatura* sp.	**		*						
	Unio sp.	*			**					
Venerioda										
Pisidiidae	*Sphaerium* sp.				*		**	*		*
Clitellata										
Arhynchobdellida										
Hirudinidae	*Hirudo* sp.									**
Rhynchobdellida										
Glossiphoniidae	*Hellobdella* sp.	**		*	***	*		***		
ind	ind	*			*		*	**	*	
Gasteropoda										
Architaenioglossa										
Ampullariidae	*Lanistes* sp.		*	**					*	
Basommatophora										
Lymnaeidae	*Galba* sp.			*		*				*
	Stagnicola sp.		*							
Physidae	*Aplexa marmorata*	*			**		*	*		
	Physa acuta	*		**	**		*	*	*	
	Physa marmorata	*			**					
Planorbidae	*Biomphalaria Pfeifferi*	***	**	***	***		**	**	**	
	Bulinus sp.	*		*	**	**	*	**	**	

	Indoplanorbis exustus				*					
	Planorbis sp.				*					
Myoida										
Corbulidae	*Corbula* sp.			*					*	
Neotaenioglossa										
Bithyniidae	*Gabbiella africana*								*	
thiaridae	*Melanoides turberculata*	***	**	***	***				**	**
Neritopsines										
Neritidae	*Neritina* sp.									*
Insecta										
Coleoptera										
Dytiscidae	*Agabus* sp.	*		*	**		*			
	Bidessus sp.						*			
	Copelatus sp.	*				**				
	Dupophilus sp.					*	*			
	Hydaticus sp.	**		*	**			*	**	**
	Hydrovatus sp.	*								
	Hyphydrus sp.	*					*			
	Laccomis sp.			*						
	Laccophilus sp.	**		**	***		**			**
	Neptosternus guignot	**	**		**		***		*	
	Yola sp.				*					
Elmidae	*Elmis* sp.						**			*
	Esolus sp.	*			*					
	leptelmis sp.	**	**	*	*	*	**	**		
	Limnius sp.	***	*	***	**	*	**	*	*	*
	Macronychus sp.	**			*					
	Potamophilus sp.	*		*						
Eubriidae	*Eubrinax*	*								
Gyrinidae	*Orectogyrus* sp.	**		**	***	*	**	**		
Haliplidae	*Haliplus* sp.	*		*	*		**			
hydrophilidae	*Amphiops* sp.	**			*			*		
Insecta										
Coleoptera										
hydrophilidae	*Berosus* sp.						*			
	Enochrus sp.	**		*	**		**	*	*	
	Hydrobius sp.	*						*	*	
	Hydrocara sp.	*			*					*
	Hydrophilus sp.	*							*	
Hydroscaphidae	*Hydroscapha* sp.					*				
Noteridae	*Hydrocanthus* sp.	**			*					
	Neohydrocoptus sp.									*
Psephenidae	*Psephenus* sp					*				
Diptera										
Athericidae	*Atherix* sp.	***	**	**	***	**	**			*
Ceratopogonidae	*Bezzia* sp.		**		*	*	**			*
	Dasyhelea sp.	*		*						
Chinonomidae	*Ablabesmya* sp.	*					*	**	*	*
	Chironomus sp.	***	**	**	***	*	***	*	*	**
	Clinotanypus sp.	*		*						
	Cricotopus sp.				*					
	Cryptochironomus sp.	*	**	**	**	*	***	*		
	Nanocladius sp.						*			
	Nilodorum sp.	*								
	Polypedilum sp.	**	**	**	**	*	**	**	**	
	Procladius sp.	**								
	Stenochironomus sp.				*				*	
	Stictochrononuis sp.	*					*			
	Tanypus sp.			*	**	*	*		**	**
	Tanytarsus sp.	*								*
Culicidae	*Culex* sp.	**			**				*	**
Limoniidae	*Hexatoma* sp.	**	*	**	*			*	*	**
	Limonia sp.	*		*	*		**			
Simuliidae	*Simulium* sp.			*	*	*	*			
Tabanidae	*Tabanus* sp.	**		**	*		*			
Tilupidae	*Antocha* sp.						*			
	Gonomya sp.			*						
Ephemeroptera										

Baetidae	*Baetis* sp.	**	**	***	***	**	***	**	**	*
	Labiobaetis sp.	***	**	***	***	**	***	***	***	***
	Pseudocloeon sp.	*			***		**	**	**	
Caenidae	*Caenis* sp.	***	**	***	***	**	***	**		***
	Caenomedea sp.						*			
Heptageniidae	*Afronorus* sp.	**		***	**	**	***	**		*
	Heptagenia sp.			*	*					
	Notonurus sp.	**		**		*	*	*	*	
Leptophlebiidae	*Adenophlebia* sp.	*	*	*		*	*		*	
	Adenophlebiodes sp.	***	**	***	***	***	***	***		***
	Chloroterpes sp.			**	*	*	*		*	
	Euthraulus sp.	*				*	*			
	Habroleptoides sp.					*				
	Habrophlebia sp.									*
	Leptophlebia sp.							*		
Leptophlebiidae	*Paraleptophlebia* sp.	*		*	**	*		*		
	Thraulus sp.	**		**	*	*	**	*		*
Oligoneuriidae	*Oligoneuriella* sp.			***	*	*		*		
Polymitarcyidae	*Povilla* sp.			*						
Tricorythidae	*Dicercomyzon* sp.	**		**	***	*	***	**		
	Machadorythus sp.			*						
	Tricorythus sp.			**	**		*			
Heteroptera										
Belostomatidae	*Diplonychus* sp.	**		**	***	*		**	*	
	Limnogeton fieberi				*				*	
Corixidae	*Corixa* sp.		*				*	*		
	Micronecta sp.	**					*		*	
	Sigara sp.						*			
Gelastocoridae	*Gelastocoris* sp.						*			
Insecta										
Heteroptera										
Gerridae	*Eurymetra* sp.	***	***	**	**	***	***	**	**	**
	Gerris sp.	*								*
	limnogonus chopardi	*	*	**	**	*	**	***	***	***
	Nanoandelus sp.		**			**	**	**	*	*
	Neogerris sp.					*		*	*	**
	Rhagadotarsus sp.	**	**	*		**	*	**	*	**
Hydrometridae	*Hydrometra* sp.	*								
Mesoveliidae	*Mesovelia* sp.		**		**	*	**		**	
Naucoridae	*Laccocoris* sp.			**					*	
	Macrocoris sp.	*								
	Naucoris sp.			*	*					*
Nepidae	*Laccotrephes* sp.	*			*					
	Ranatra sp.			**	**				*	
Notonectidae	*Anisops* sp.	**	**		*	**	*	**	***	***
	Enithares sp.		*		*	*	**	**	**	***
	Nychia sp.	*				*	**	*	**	**
Ochteridae	*Ochterus* sp.			*			*			*
Paraphrynovelidae	*Paraphrynovelia* sp.	**		*			*		*	
Pleidae	*Plea* sp.			*						
Veliidae	*Microvelia* sp.	***	*		*	**	*	*	*	
	Rhagovelia sp.	**	**	*	*	**	**	**	**	**
Veliidae	*Velia* sp.	**	*	*		*		*		**
Lepidoptera										
Pyralidae	*Pyralidae*	*	*		**	*	**			*
Odonata										
Calopterygidae	*Phaon iridipennis*	*		*	*	**	**	**	*	
	Sapho bicolor	*							*	
Chlorocyphidae	*Chlorocypha* sp.	**	*	**	**		**	*		
Coenagrionidae	*Ceriagrion* sp.	**	*	**	**	**	**	**	**	
	Coenagrion sp.			*						
	Enallagma sp.	*		*	***	**	*	**	**	
	Erythromma sp.	**		**			*	*		
	Pseudagrion sp.	***	*	***	***		***	**	***	*
Macromiidae	*Phyllomacromia* sp.	***	**	***	**	**	***	***		**
Gomphidae	*Gomphidia* sp.	*								
	Gomphus sp.								*	
	Ictinogomphus sp.				*					

	Lestinogomphus sp.			*	**		*	*		**
	Microgomphus sp.			*			*			
	Neurogomphus sp.			*						*
	Onychogomphus sp.				*	*				
	Paragomphus sp.				*	*	**			
	Phyllogomphus sp.	**		*	*	*	**			*
Lestidae	*Lestes* sp.			*						
Libellulidae	*Brachythemis* sp.	**	*	**	**	*	**		*	**
	Chalcostephia sp.								*	
	Libellula sp.				*					*
	Olpogastra sp.	***		**	*	*	**	*	*	*
	Orthetrum sp.	*	*							
	Pantala sp.				*					
	Parazyxomma sp.			**						
	Parazyxomma flavicans								*	
	Tholymis sp.				*					
	Trithemis sp.			*	**		*		*	
	Zygonyx sp.	**		***	*	*	**	*	*	
	zyxomma sp.				**					
Platycnemididae	*Platycnemis* sp.	*							**	
	Spesbona sp.	***		***	***			**	**	
Synlestidae	*Chlorolestes* sp.				*					
Orthoptera										
Tridactylidae	*Tridactylus* sp.					*				
Plecoptera										
Perlidae	*Neoperla spio*			**	*	***	**	*		
Insecta										
Trichoptera										
Dipseudopsidae	*Phylocentropus* sp.			*						
	Dipseudopsis sp.						*			
Ecnomidae	*Ecnomus* sp.	***	**	*	*	*	**	**		*
Goeridae	*Goera* sp.			*	*			*	*	
Hydropsychidae	*Cheumatopsyche digitata*	**		*	**					
	Hydropsyche sp.						*			
	Polymorphanisus sp.		**	*				*		
	Protomacronema sp.			*						
Hydroptilidae	*Hydroptila* sp.	*								
Leptoceridae	*Adicella* sp.				*			*		
	Athripsodes sp.			**			**			*
	Ceraclea sp.	*	*	**	***	**	**	**	*	**
	Homilia sp.	*								
	Leptocerus sp.	***		***	***	*	**	*		
	Oecetis sp.		*	**	***	**	**	*		
	Paracetodes sp.							*	*	
	Setodes sp.		*	**	**	*	**			
Philopotamidae	*Chimarra* sp.		**	**		**	**	*		
Malacostraca										
Decapoda										
Atyidae	*Caridina africana*	***	*	***	**		***	**		**
	Caridina nilotica		**	**		**	*	*	**	
Desmocarididae	*Desmocaris trispinosa*	*	**	**	**		**	*	**	**
Palaemonidae	*Macrobrachium macrobrachium*			*		*				*

The pH of the water varied within GI between 6.19 and 8.36. Water pH was significantly different among the groups of sampling sites (Mann-Whitney test, *p*-value < 0.05). The Temperature was between 25.2 °C to 30.8 °C. These values were obtained in GI. However, there were no significant difference among GI and GII (Mann-Whitney test, *p*-value > 0.05).

The value of dissolved oxygen fluctuated between 1.42 mg/L (GII) to 9.92 mg/L (GI). For this parameter, there were no significant difference among GI and GII (Mann-Whitney test, *p*-value > 0.05). For the Conductivity value, the high value 342 µS/cm was obtained at GII and the low value 59.1 µS/cm was obtained at GI. There were significant difference among the groups (Mann-Whitney test, *p*-value < 0.05). According to the Nitrites value, the high value 0.12 mg/L was obtained at GII and the low value 0.002 mg/L was obtained at GI. Nitrites values were significantly different among GI and GII (Mann-

Whitney test, *p*-value < 0.05). The value of the Nitrates shown significant differences between GI and GII (Mann-Whitney test, *p*-value < 0.05). This value varied from 3.2 mg/L at GI to 22.7 mg/L at GII. Ammonium was between 0.01 mg/L to 1.92 mg/L at GII. For this abiotic parameter, significant difference was notified between GI and GII (Mann-Whitney test, *p*-value < 0.05).

The highest value of phosphorus (0.55 mg/L) and the lowest (0.02 mg/L) was obtained at GII. As far as is concerned phosphorus there were significant differences between the groups.

Taxonomic richness

A total of 187 taxa of aquatic macroinvertebrates was collected across all nine sites (Table 4). These macroinvertebrates were grouped into 6 classes (Arachnida, Clitellata, Bivalvia, Gasteropoda, Insecta and Malacostraca) (Fig. 5), 20 orders and 77 families. Insecta was the most diverse class with 161 taxa (85.63%), and comprises 9 orders and 59 families. In this class, Heteroptera comprised 13 families and was the most well represented order, however the order Odonata with 9 families had more than taxa (34). Insecta was followed by Gasteropoda (05 orders) whitin it Basommatophora (3 families) was well represented order. Classes of Clitellata (3 orders), Bivalvia (2 orders), Arachnida (1order) and Malacostraca (1 order) were lest diversified.

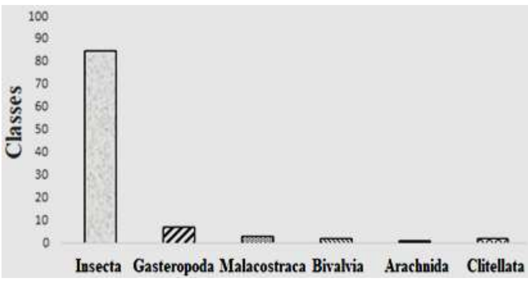

Fig 5. Distribution of aquatic macroinvertebrates Classes collected in the Mé River in 2022

Macroinvertebrate structures

Macroinvertbrate structure of Mé River was showed in Fig. 6. Overall, Shannon diversity index, and Rarefied richness varied significantly between groups (Mann-Whitney test, *p*-value < 0.05). Piélou's index was between 0.98 (GII) to 0.59 (GI). Shannon index ranged from 3.37 to from 0.69. Both values were obtained in GII. For Rarefied richness, the high value (2) was obtained at GII and the low value (1.44) was obtained at GI. The relatively higher value for each index was obtained in GII.

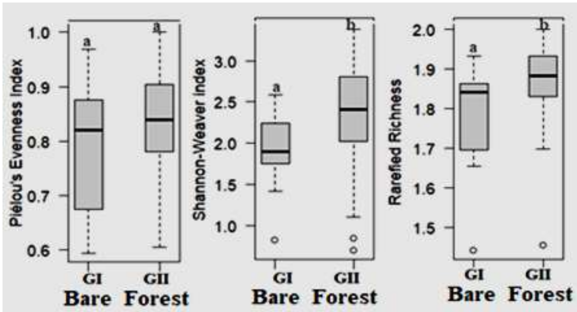

Fig. 6. Boxplots showing differences in diversity indices (Piélou's Evenness index; Shannon Weiner index and Rarefied Richness) between group sites during the study period, boxplot with common letter (a) do not differ significantly (Mann-Whitney, *p*-value > 0.05)

Water quality

All water quality indices calculated at each sampling sit have been compiled and presented in Table 5. The EPT index was varied between 12.12% (GI) and 33.78 % (GII). Ratio_EPT_Chironomidae index was between 59.15 and 94.73. Both values were obtained in GII. The WQI values was ranged from 33.70 (GI) to 202.02 (GII). The proportion of Baetidae was estimated to be between 9.15 and 88.23 .Both values were obtained in GI .The Chironomidae index was ranged from 1.70 % (GII) to 13.82 % (GI). According to these indices water quality was good in GII (S3, S4); poor in GII (S5) and GI (S8); unfit for consumption in GII (S2)

Relationship between land use and water quality

According to the focused PCA (Fig. 7), the rings get closer to the center they reflect a higher correlation with the dense forest (FD) or bare ground (BG). On the left part, WQI and Ratio_EPT_Chironomidae showed the strongest significant correlation with the dense forest. Ratio_EPT_Chironomidae was negatively correlated with dense forest, whereas WQI was positively correlated with dense forest. The EPT index was negatively correlated with dense forest. In contrast, the Chironomidae and Baetice indices were positively correlated with dense forest. On the right part, the Ratio_EPT_Chironomidae and the EPT index were positively correlated with bare ground. Conversely, the Chironomidae, Baetidae indices and WQI were negatively correlated with bare ground. No significant correlation between these indices and bare ground has been reported.

Table 5. Index of taxa and their abundance at each sampled site

Sites	Index				
	EPT	Ratio_EPT_Chiro	WQI	Pcent_baeti	Pcent_Chiro
S1	26.34	65.58	42.59	43.81	13.82
S2	13.72	59.15	202.02	57.14	9.47
S3	27.39	94.15	41.91	27.47	1.70
S4	25.70	80.04	41.89	50.16	6.40
S5	33.78	94.73	104.17	15.18	1.87
S6	33.43	87.39	64.74	31.21	4.82
S7	26.19	85.18	38.47	39.56	4.55
S8	12.12	71.79	33.70	88.23	4.76

E= Ephemeroptera; T= Trichoptera; P = Plecoptera; Chiro = Chironomidae; Baeti = Baetidae; Pcent = Percentage; WQI = water quality index

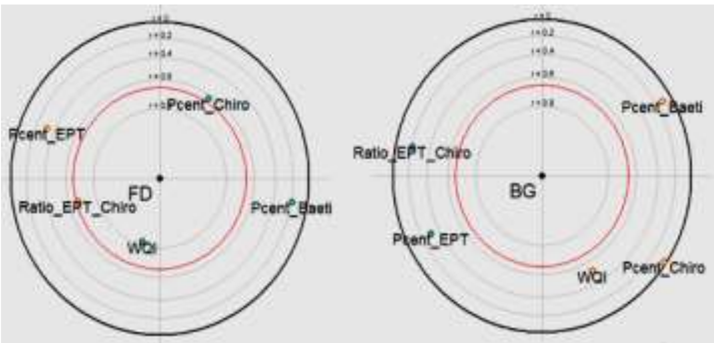

Fig. 7. Focused PCA of the relations between the class of land use and water quality
On the left part, a focused PCA of the FD class of land use and water quality. On the right part, a focused PCA of the BG class of land use and water quality: WQI=water quality index; Ratio_EPT_Chiro=(EPT/(EPT+Chironomidae))*100; Pcent_Chiro=(Chironomidae/all taxa)*100; Pcent_Baeti =(Baetidae/Ephemeroptera)*100 ; BG=Bare Ground; FD=Dense Forest.

DISCUSSION

The land use study showed a high proportion of bare ground in GI (45% of the total area at each site). This proportion of bare ground could be explained by significant urban expansion, which contributes to deforestation. Sites in GII were characterized by high proportion of tree crops and dense forests (40% of their total area, across all land-use classes). This result would suggest that these sites are subject to extensive farming, which also contributes to deforestation. These finding are consistent with the work of Bi Zamble *et al.,* 2023. He showed that the Mé River watershed is characterized by extensive agriculture which has led to deforestation of 18% of dense rainforest.

Analysis of the abiotic parameters of the groups obtained from HCA showed that Phosphorus, Nitrites and Ammonium were significantly higher in GII. The use in agriculture of nitrate and urea as fertilisers could explain the high levels of these nutrients. These findings are consistent with those of Gorgoglione *et al.* 2020 who identified a correlation between nutrients concentration levels and agricultural practices. Yet agriculture and overexploitation of forest are the main causes of deforestation in Côte d'Ivoire (Kouassi *et al.*, 2021).The temperatures (25.2 -30.8°C) recorded in Me River are typicaly of tropical rivers in forested areas. This is similar to that of Agneby River (25.50 – 28.05 °C) in Côte d'Ivoire determined by Diomandé *et al.* (2009). However, the high temperature recorded (30.8°C) in (GI) is thought to be due to the absence of canopy caused by deforestation. The water is directly exposed to the sun's ray, which raise the water temperature (Edia, 2008; Camara *et al.*, 2012).

A total of 187 taxa of aquatic macroinvertebrates was collected. Insecta was the most diverse class (09 orders). Insecta constitutes the majority of the fauna with 161 taxa (85.63%).This taxonomic richness is thought to be due to the presence of large amounts of plants debris which provides a varied food source and shelter from predators. Camara *et al.* (2012) demonstrated a positive correlation between taxonomic richness and plants debris in the river within Banco National Park. This proportion of the insects (85.63%) is similar to that of Ouattara *et al.* (2020), namely 84.78%.

Ecological indices varied significantly between the groups. Shannon diversity index (3.37) and Rarefied richness (2) were significantly higher in GII. The aquatic macroinvertebrates found in this group were most diversified which could reflect good water quality at these sites. The lowest values of these indices in GI could indicate that the sites of this group was impacted. Studies have shown that human activities are largely responsible for the degradation of aquatic ecosystems, either through the discharge of polluants (Stubblefield *et al.*, 2005) or through habitat altération linked to déforestation (Haddad *et al.*, 2015).

The low proportion of EPT in GI (13.72%) could be explained by the change to their terrestrial habitat from deforestation. Törnblom *et al.* (2011) showed that the proportion of sensitive taxa like Plecoptera has highly correlated with percentage of forest and EPT declines with deforestation (Nina *et al.*, 2025). The low percentage of EPT recorded in GI would suggest that water quality at these sites has deteriorated.

The relative high WQI values in GII (202.02) would indicate deterioration in the ecological quality of the water due to chemical pollutants. Some sites in GII were deemed unfit for consumption. These sites were characterized by gold mining and the intensive use of fertilizers. Contamination of water and sediments reduces the abundance and species richness of macroinvertebrate communities and alters their structure (Capparelli *et al.*, 2021). These finding are consistent with those of Ayiwouo *et al.* (2022).

The water quality and low taxonomic diversity in GI could be explained by sedimentation due to deforestation. In the absence of riparian forest, some sites in GI receives wastewater and more sediments directly from urban areas. Sediments through their abrasive action can damage sensitive parts such as gills and filtration systems, making breathing and feeding difficult (Wood *et al.*, 2005**)**. Sediments also carry pollutants that have a negative impact on the structure of the macroinvertebrates (Townsend *et al.*, 2009). This could explain the low taxonomic diversity of macroinvertebrates (EPT) (Balata *et al.*, 2007) in GI.

Pollutants resulting from human activities raise the WQI, hence the positive correlation observed between FD and WQI. These pollutants have a negative impact on the more sensitive Ephemeroptera, whilst favouring more resistant taxa, which would explain the positive correlation between FD and the Baetidae and Chironomidae. These observations confirm those of Lee *et al.* (2025), who showed that the EPT proportion decreased significantly with higher level total nitrogen and agricultural practice. Some of the GI sites are bordered by bamboo groves which constitute significant riparian vegetation. The bamboo plants absorb the nutrients from the wastewater and provide a food source and habitats for organisms, thereby creating local conditions favorable (Kasahara *et al.,* 2025; Najihah *et al.,* 2026) to pollution sensitive organisms to the detriment of pollution-resistant organisms. This therefore highlights the importance of the forest for water quality.

CONCLUSION

Overall, the sites presented good ecological water quality. However, abiotic parameters indicated that some sites in GII exhibited poor ecological status. Conversely, biotic parameters have shown that the macroinvertebrates in GII possess a high capacity for resilience to moderate disturbances. Consequently, GII recorded a greater number of sensitive taxa. In contrast, GI, due to the lack of vegetation cover resulting from deforestation linked to urbanization, has a low proportion of sensitive taxa (EPT). Deforestation therefore appears to have an impact on the most sensitive taxa.

It is therefore necessary to use the bioecological traits of these taxa to better understand the impact of deforestation on the ecological quality of the Mé River.

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