Review Article

The lake city of Ganvié in the face of environmental development challenges: a review of the literature

ABSTRACT

Ganvié is a lake city in Benin, West Africa, known for its unique architecture and culture. However, the city is facing numerous environmental challenges that threaten the livelihoods and culture of its inhabitants. This article presents a comprehensive literature review of the environmental challenges facing Ganvié, their drivers, consequences, existing interventions and policies, and potential solutions.

Keywords: Environmental challenges, pollutions, sustainabledevelopment, Ganvié, Lake Nokoué

1. INTRODUCTION

The lake town of Ganvié, located in the Republic of Benin, is facing significant environmental challenges due to climate change, population growth and unsustainable human activities. The town, once known for its thriving fishing industry and unique way of life, is now at risk of disappearing due to rising water levels and pollution of the lake that surrounds it. The objective of this desk study is to explore the environmental challenges facing the lake town of Ganvié and to identify potential solutions that can help mitigate the impact of these challenges.

The study will aim to answer the following research questions:

- What are the environmental challenges facing the lake town of Ganvié, and how have they changed over time?
- What are the main drivers of these environmental challenges and how have human activities contributed to them?
- What are the potential consequences of these environmental challenges on the people of Ganvié, their livelihoods and their culture?
- What are the existing interventions and policies to address the environmental challenges facing Ganvié, and how effective have they been?
- What are potential solutions and strategies that can be implemented to mitigate the impact of these environmental challenges on Ganvié and its inhabitants?

In answering these research questions, the study will provide a comprehensive literature review of the environmental challenges facing the lake town of Ganvié, and identify potential solutions and strategies that can be implemented to mitigate their impact. This will contribute to the knowledge base on the challenges faced by lake towns and provide insights on how they can be sustained in the face of environmental change.

2. METHODOLOGY

A review or synthesis of relevant literature is an important aspect of any scientific study. It is a solid basis for the advancement of knowledge related to a specific topic or problem. In the framework of the present work, it aims at researching, grouping, synthesizing and consolidating existing scientific contributions on ~~the~~ state of degradation of environmental components in ~~the~~lacustrian city of Ganvié and, more broadly, in Lake Nokoué, which occupies more than 80% of it. We have indeed conducted a literary and textual analysis of several scientific articles and reports dealing with the components and associated factors of this degradation. Each article was read and analyzed using grids developed specifically for the study and corresponding to each of the research objectives.In addition, field observation was conducted to confirm some of the realities presented in the literature.

3. RESULTS AND DISCUSSION

3.1. RESULTS

Although this study focuses on Ganvié, it tends to broaden the scope of analysis to Lake Nokoué. Indeed, Ganvié, as a lake territory populated by *Toffinu* (literally "men of the water"), can only be understood as a component of a larger space: the commune of So Ava and more broadly Lake Nokoué.

The most important lake city in West Africa, Ganvié, whose name means "we survived" in Fon, was created by people who fled from slave kidnappings (AFD, 2018). Listed as a World Heritage Site by the United Nations Educational, Scientific and Cultural Organization (UNESCO) since 1996, this territory inhabited by the *Tofinu*, otherwise known as "men of the water," extends over two arrondissements of the commune of Sô-Ava and is characterized by an atypical development around water, on and around Lake Nokoué (ACED, 2018). Ganvié concentrates according to the last general census a~~of~~ population and houses ~~ing~~ 37,172 inhabitants of which 51.7% are men (19,215) and 48.3% are women (17,957); that is, more than 30% of the total population of the commune of So Ava. It includes about 6,000 dwellings spread over an area of 200 ha (INSAE, 2015).Ganvié is therefore characterized by a low density of 17 inhabitants per ha on average.

Lake Nokoué is the main contributor to inland fisheries in Benin (Lalèyè et al., 2003), and provides more than 80% of the total production of the water bodies of the three departments of southern Benin. It is also the most productive lake in West Africa. However, the occupation of the shores of Lake Nokoué and the Porto-Novo lagoon has changed significantly over the past few decades. Indeed, the environment of the lagoon complex, once dominated by lush vegetation, is nowadays mainly urbanized with the presence of 8 communes along its shores (Cotonou, Abomey-Calavi, Sô-Ava, Aguégués, Dangbo, Adjarra, Porto-Novo, and Sèmè-Kpodji). The cities of Cotonou and Abomey-Calavi are located respectively on the southern and western shores of the lake and have more than 2 million inhabitants. Several lake villages were historically built on piles, notably the villages of Ganvié, So-Ava, So-Tchanhoue, So-Zounko, Vekki, HouedoGbadji, Ahomey-lokpo, Zoungamè and Houedomè. The population density around the lake (about 4000 people/km2) is nowadays largely superior to that of the Ouémé watershed (about 100 people/km2). This strong peri-lake urbanization has constantly increased the anthropic pressure on the hydrodynamic and ecosystemic functioning of the lake (Mama, 2010): massive discharges linked to human activities, eutrophication, contamination and pollution, filling of the lake, modification of ecosystemic habitats, pressure on the halieutic resource, decrease of biodiversity, etc.

The figure below shows the commune of So-Ava, which is partially occupied by Lake Nokoué, including the districts of Ganvié 1, Ganvié 2 and Vekky.

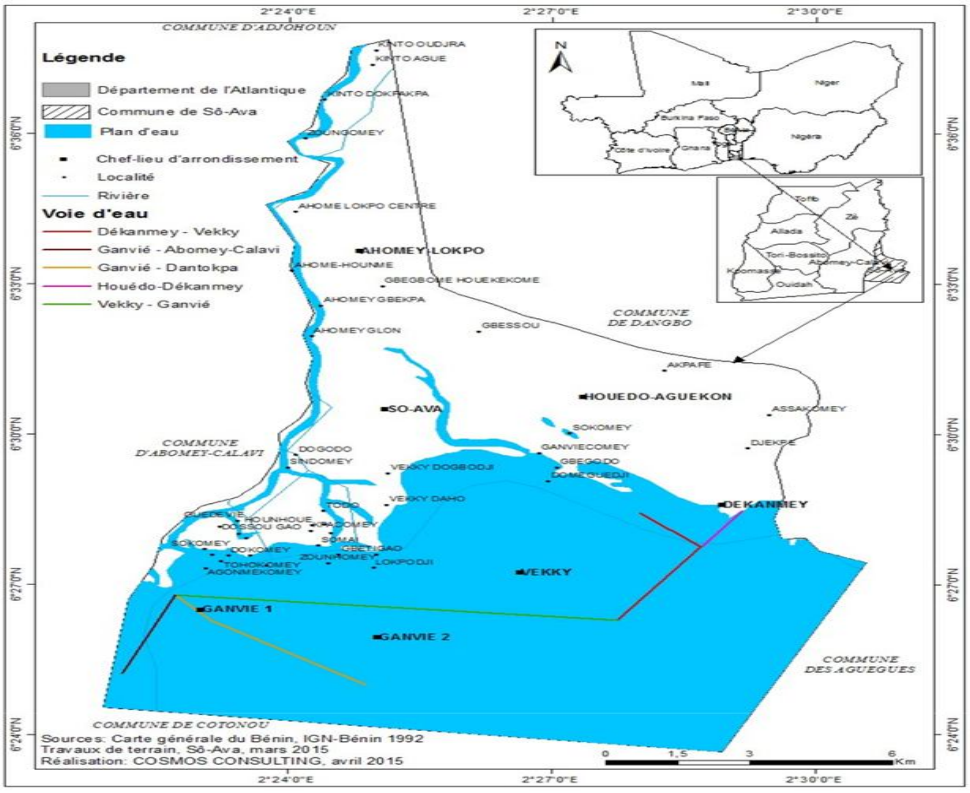

Fig. 1. Geographical location of the commune of Sô-Ava

It is quite clear that Lake Nokoué occupies more than 80% of the lakeside city of Ganvié.The lake is an inhabited land: the cities that border it advance on this great expanse of water in lacustrine and semi-lacustrine villages on stilts. It's history is that of a refuge: since 1650, various migratory flows fleeing fratricidal wars or slave hunters would have fed its settlement. The main contributor to continental fishing in Benin (Lalèyè et al., 2003), Lake Nokoué provides more than 80% of the total production of the water bodies of the three departments of southern Benin. It is also the most productive lake in West Africa (AFD, 2018). However, the occupation of the shores of Lake Nokoué and the Porto-Novo lagoon has changed significantly in recent decades. Indeed, the environment of the lagoon complex, once dominated by lush vegetation, is nowadays mainly urbanized with the presence of 8 communes along its shores (Cotonou, Abomey-Calavi, Sô-Ava, Aguégués, Dangbo, Adjarra, Porto-Novo, and Sèmè-Podji). The cities of Cotonou and Abomey-Calavi are located respectively on the southern and western shores of the lake and have more than 2 million inhabitants. Several lakeside villages were historically built on stilts, notably the villages of Ganvié (the most famous), So-Ava, So-Tchanhoue, So-Zounko, Vekki, HouedoGbadji, Ahomey-lokpo, Zoungamè and Houedomè. The population density around the lake (about 4000 people/km^2) is nowadays largely superior to that of the Ouémé watershed (about 100 people/km2). This strong peri-lake urbanization has constantly increased the anthropic pressure on the hydrodynamic and ecosystem functions of the lake (Mama, 2010): massive discharges linked to human activities, eutrophication, contamination and pollution, filling of the lake, modification of ecosystem habitats, pressure on the fishery resource, decrease in biodiversity, etc.

Fig.2. Aerial view of space occupation in Ganvié

It should be noted that Lake Nokoué is an integral part of Ramsar site 1018. This site has been designated since 2000 and was extended in 2018 from 91,600 ha to 652,760 ha. It includes, as indicated on the Ramsar Sites Information Service (RSS) webpage, various ecosystems including swamp forest, flooded grasslands, reeds, floating vegetation and mangroves.

3.1.1. Main environmental problems in Lake Nokouéand associated factors

3.1.1.1. Hydrological and hydrodynamic regime

The average volume of Lake Nokoué is about 250 million m3, typically varying between 150 and 325 million m3 (Colleuil and Texier, 1987). The hydrological regime of Lake Nokoué, directly influenced by the rainfall regime, is characterized by three main periods: a period of low tide from December to mid-May, a period with a slight increase in level between June and August caused by intense rainfall, and a period of high tide from September to November mainly due to inflows from the Ouémé basin.

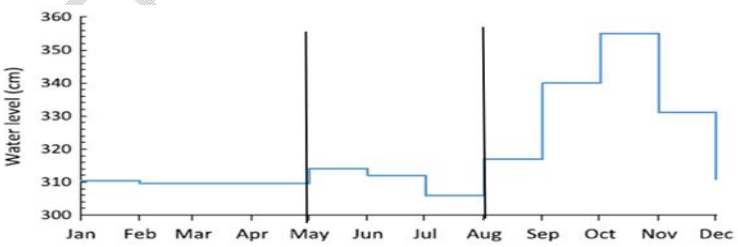

Fig.3. Average monthly water level of Lake Nokoué (data from 2001-2010)

The water level of the lake is influenced by the inflow from the two main rivers, the Ouémé and the Sô, which control the inflow of fresh water into the lake, and the Cotonou Canal, which controls the exchange with the Atlantic Ocean and thus the salinity level.

As shown in the Figure above, during the low tide period, the intrusion of sea water is greater than the inflow from the rivers, so the whole lake has a high salinity, with an average value of about 15 ppt. On the contrary, during the high tide period, when the inflow from the rivers is higher, the salinity level decreases sharply: the salinity inside the lake varies from 0.4 ‰ (at the mouth of the tributaries) to 2 ‰ (at the Cotonou canal).(Cite the authors to salt

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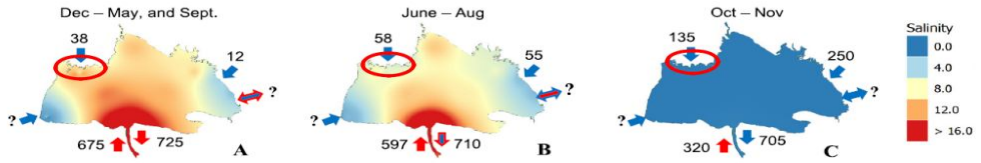

Fig.4. Reference hydrological period and salinity variations (in ‰) of Lake Nokoué
Numerical values represent water flows (in m^3 / s) from tributaries and between the lake and the Atlantic Ocean. The "?" represents unknown flow values. Blue arrows represent freshwater inflow while red arrows represent saltwater intrusion or outflow. A = low tide period, B = intermediate period and C = high tide period.

The bottom of Lake Nokoué is mainly muddy, especially in the west, around Ganvié, and in the deep areas of the center. 75% of these muds are dark gray and 30% of this facies contains a high content of plant debris from acadjas (Mama et al., 2011). The acadjas, artificial parks made of a large quantity of branches, aim to reproduce the natural habitat found in mangrove areas. They allow the creation of refuge and reproduction zones for ichthyofauna (Villanueva et al., 2006), but the degradation of this organic matter of continental origin depletes the lake in oxygen, modifies the composition of the sediments, and favors the filling of the lake. Organic matter levels recorded in lake sediments vary from 8 to 15% and are generally higher around lake villages (Mama et al., 2011),

3.1.1.2. Water quality

Lake Nokoué has been the subject of several monitoring campaigns in order to de-escalate its chemical and ecological status: this section therefore presents the data collected on temperature, transparency, pH, dissolved oxygen, nutrients, BOD, COD, and heavy metals, indicating, when available, the data concerning the town of Ganvié. In general, a deterioration in water quality is observed during the low tide period, when the highest values of BOD, **COD, nitrate, phosphate and salinity are recorded.**

- **Temperature:** The surface water temperature of Lake Nokoué varies between 23°C and 34°C and due to the shallow depth of the lake (Gnohossou, 2006); there is no temperature stratification along the vertical(Lalèyè et al. , 2003)..
- **Transparency**: The waters of Lake Nokoué have experienced a decrease in average transparency compared to what was measured in the 1990s, due to the increasing eutrophication of the lake and the increase in turbidity of the Ouémé River, caused in turn by the increase in agriculture in the basin. In the 1990s, transparency values were 1.46 m during the high tide period and the minimum recorded was 1.06 m. In contrast, data collected in 2015 show a decrease in these values: at high tide, the value fell to 0.90 m and the minimum value recorded was 0.3 m.
- **pH:** Lake Nokoué is slightly alkaline with pH values varying between 8.5 and 6.5: these values are typical of natural water bodies (WHO standards).
- **Dissolved oxygen:** Dissolved oxygen measured at the surface varies between 9.1 mg/l and 0.5 mg/l with higher values during the high tide period. Significant differences between day and night were also recorded: in particular, the lowest values occur in the early morning (0.5 mg/l), especially in densely populated areas such as Ganvié, and then increase progressively during the day to 7 mg/l. The sharp decrease in dissolved oxygen concentration during the night could be a sign of strong respiratory activity in the lake, but could also be explained by the high organic

matter content in some places like Ganvié. According to WHO standards, concentrations below 5 mg/l can affect the functioning and survival of biological communities, and if below 2 mg/l, it can even lead to the death of most fish. Although Lake Nokoué is shallow, the difference in concentration between the surface and the bottom appears to be significant, especially in some areas, including Ganvié. In particular, oxygen concentrations of 7.7 to 1.7 mg/l were recorded at the surface and 6.23 to 0.08 mg/l at the bottom. This could indicate high deposition followed by decomposition of organic matter at the bottom of the lake.

- **Nitrogen:** Measurements indicate that total nitrogen (TN) in the lake ranges from 3.9 mg/l to 9.1 mg/l, while total phosphorus (TP) ranges from 0.05 mg/l to 2.30 mg/l. Dissolved inorganic nitrogen (N-NO3 + N-NH4) ranges from below the detection limit to 6.8 mg/l. During the high tide period, the main source of N and P in Lake Nokoué is the Ouémé River, which contributes about 90% of the TN. In contrast, at low tide, the Sô River contributes about 75% of the TN. Several authors (Belfrid et al., Djihouessi et al. indicate the years) confirm that the tributaries represent the main nutrient inputs. All values are above the limits of the WHO standards for surface waters and are typical of waters receiving untreated wastewater discharges. Indeed, in addition to the inflow from the tributaries, the lake receives nutrients from untreated wastewater mainly from three sources: the village of Ganvié (more than 40,000 inhabitants), the city of Abomey-Calavi located to the west (more than 700,000 inhabitants) and the city of Cotonou (more than one million inhabitants). In addition, the lack of riparian vegetation has encouraged the proliferation of "illegal" dumpsites on the shores of Cotonou and Abomey-Calavi, which likely increase the N and P enrichment of the lake through surface runoff. In addition to these contributions, there is also that related to the presence of water hyacinth: in particular, as indicated in the 2011 study by Mama et al. the highest values of total N occur during the dry season period, when the increase in salinity causes the death of water hyacinth and thus the increase of N in the water column. However, it is not yet clear what role nutrient inputs from untreated sewage, landfills, and water hyacinth decomposition play in quantitative terms relative to tributary inputs.
- **Phosphorus:** The orthophosphate value measured in the lake (P-PO4) varies from below the detection limit to 0.62 mg/l. During the high tide period, the main source of P in Lake Nokoué is the Ouémé River, which contributes about 60% of the lake's TP. In contrast, during low tide, the Sô River contributes about 95% of the TP. Several authors (Belfrid et al. 2017, Djihouessi et al. 2018 (you could add more authors since you have indicated several)) confirm that the tributaries represent the main nutrient inputs. In particular, according to Mama et al(year). the Ouèmè River plays a key role: as the basin is essentially agricultural, runoff carries a high phosphorus content due to the fertilizers used in cotton plantations. In addition, untreated wastewater and runoff from illegal dumping areas contribute, but their contribution is not quantified. All values are above WHO surface water standards and are typical of waters receiving untreated effluent discharges.
- **BOD(Biological Oxygen Demand):**His values in the lake range from 1 mg/l to 29 mg/l. The measurement points located in the town of Ganvié show values between 5 mg/l and 20 mg/l with higher values during periods of low runoff (Zandagb et al., 2016). Vodougnon et al. (2018) also confirmed these values where the average BOD concentration measured in 2015-2016 was 10 mg/l. According to WHO water quality standards, these concentrations are typical of waters receiving effluent and can reach even higher values, especially near the point of discharge. As indicated in the study conducted by Mama et al. in 2011, the highest BOD values are recorded in February and in general during low tide months: during this period, in fact, the increase in salinity causes the death of the water hyacinth, whose decomposition leads to an increase in BOD.

- **COD (Chemical Oxygen Demand):** His values recorded in the lake vary between 3.67 and 540.63 mg/l. The Ganvié sites have values between 20 mg/l and 170 mg/l with higher values during periods of low runoff (Zandagb et al., 2016). Vodougnon et al. (2018) also confirmed these values where the average COD concentration measured in 2015-2016 reached a value of 212 mg/l. According to the WHO water quality standard, these concentrations are typical of waters receiving effluent.
- **Pesticides:** The quantity of pesticides used in the Ouémé basin is constantly increasing: in the Ouémé delta and Lake Nokoué, the presence of more than 20 categories of pesticides has been noted in both sediments and fish, with concentrations up to 1364 ng/g.
- **Heavy metals:** Numerous heavy metals were found in the lake, including zinc (43.40-85.26 mg/l), cadmium (9.17-21.78 mg/l), mercury (0.62-2.16 mg/l), lead (11.49-35.84 mg/l), copper (0.16-0.29 mg/l) and arsenic (5.84-8.35 mg/l). Heavy metal pollution has been linked to "illegal" solid waste dumping along the coasts of Cotonou and Abomey-Calavi. Other important sources of contamination are industrial and biomedical wastes discharged into the water, incineration of plastics, and oil discharges from motorized boats and illegal gasoline trafficking with Nigeria; riverside villages (such as Ganvié and Vekki) appear to be the most contaminated.

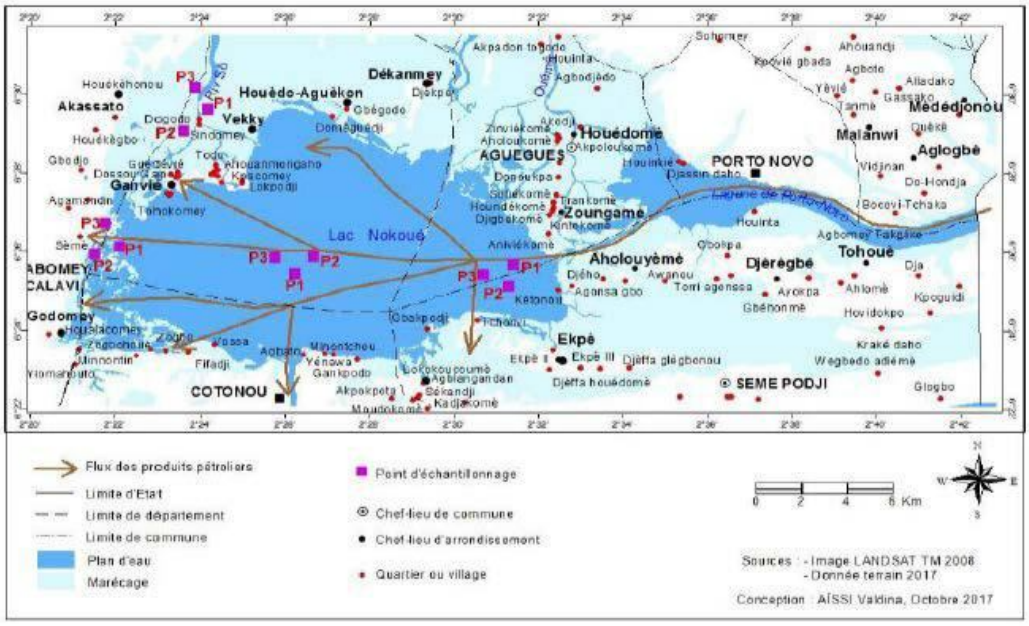

Fig.5. Main routes of petroleum products

According to Kaki et al. in the town of Ganvié, the water is mainly contaminated by arsenic, with a concentration of 6.40 mg/l compared to a WHO drinking water standard of 0.01 mg/l. Lead and copper were measured at 0.05 ± 0.01 mg/l and 0.25 ± 0.14 mg/l, respectively, which are lower than the WHO drinking water standards.

- **Fecal coliforms**: In the study conducted by Dovonou (2011), for the 2007 monitoring campaign, the presence of total coliforms was also detected in Ganvié, in quantities of 2000 coliforms/100ml in June and 4000 coliforms/100ml in September, as well as streptococci in quantities of 110 coliforms/100ml and 500 coliforms/100ml in June and September respectively. The presence of these bacteria is therefore indicative of fecal pollution of the lake.

The Table below summarizes the measured values of the main parameters: it should be noted that these values refer for the most part to data collected during the 2015-2016 period. The table also shows the WHO quality standards for ease of comparison.

Table 1. Physical, chemical and biological properties of experimental soil (0-20 cm)

Parameters	Measured value	WHO standard	Measuring point	Year of monitoring
Température	23 -34 °C	25 °C	Lac Nokoué	
pH	Eaux naturelles: 6.0 - 8.5		Lac Nokoué	
OD	0.5 - 7.0 mg/l	Natural waters: 6.0 - 8.5 > 2-5 mg/l	Ganvié	
TN	3.9 - 9.1 mg/l	Natural waters: <0.3 mg/l	Lac Nokoué	
P-PO4	Up to 0.62 mg/l	Natural waters: < 0.020 mg/l	Lac Nokoué	
TP	0.05 - 2.30 mg/l	Natural waters: <0.01 mg/l	Lac Nokoué	2015-2016
BOD	10 mg/l	Natural waters: <2.0 mg/l	Ganvié	
COD	212 mg/l	Natural waters: <20 mg/l	Ganvié	
Zinc	43.40– 85.26 mg/l	Drinking water: <3.0 mg/l	Lac Nokoué	
Cadmium	9.17–21.78 mg/l	Drinking water: <0.003 mg/l	Lac Nokoué	
Mercury	0.62–2.16 mg/l	Drinking water: <0.001 mg/l	Lac Nokoué	
Pb	0.05 ± 0.01 mg/l	Drinking water: <0.3 mg/l	Ganvié	
Copper	0.25 ± 0.14mg/l	Drinking water: <2 mg/l	Ganvié	2001
Arsenic	6.40 mg/l	Drinking water: <0.01 mg/l	Ganvié	

Source of this information

3.1.1.3. Eutrophication of Lake Nokoué

Invasive aquatic plants are a particularly important problem in the tropics and intertropics (Mitchell, 1974, 1985). Because of their extremely high growth rate, they can rapidly cover large areas and considerably modify the functioning of the ecosystems concerned. The main consequences are the limitation of light penetration, the increase of evapotranspiration, the modification of sedimentation rates, the alteration of the cycle of different nutrients, the clogging and drying of stagnant environments, and the modification of flows at the water-atmosphere interface (Etien and Arfi, 1996). In addition to this ecological damage, there are often major socio-economic effects such as the impossibility of obtaining drinking water, the proliferation of water-borne diseases, difficulties in fishing and irrigation activities, the hindrance to the movement of goods and people, etc.

Lake Nokoué is a eutrophic to hyper-eutrophic system (Mama et al., 2011; Zandagba et al., 2016), characterized in particular by the seasonal proliferation of water hyacinth (Eichhornia crassipes), which can cover up to 15% of the lake surface (Djihouessi et al., 2018). A single water hyacinth plant, which is the most invasive species in the plant world, can under favorable conditions multiply up to 60,000 plants in eight months and cover 400 m^2 (Khan and Thyagarajan, 1988). Water hyacinth appears in the lake and proliferates each year during the high water period when freshwater inflow from tributaries invades the lake. The abrupt increase in salinity after the water recession between December and January inhibits the growth of the hyacinth. The plant dies and disappears completely from the lake surface when salinity exceeds 6-7 (Lalèyè, 1995; Mama et al., 2011; Negusse and Bowen, 2010). This plant biomass degrades and sediments locally, or is transported by the hydrodynamic circulation of the lake. Decomposition of water hyacinth could be an internal source of

nitrogen and phosphorus release into the lake (Mama et al., 2011). However, the rate and magnitude of this internal recycling of nutrients that may participate in the eutrophication of the lake is not known.The plate below presents the natural environment of Lake Nokoué during the high water period:

Plate 1. Natural environment of Lake Nokoué during the high water period

3.1.1.4. The expansion of the acadjas

The acadjas are fish pens, installed in shallow water of 1.5 m at the most during the low water period. The acadjas are made up of a space staked with branches, the outside of which is surrounded by branches, hardwood and little branched. Inside the park, small enclosures of varying shapes and sizes are installed. The plant material, leaves, branches, etc. that cover the ground are generally soft and branched wood that, in water, have the property of quickly decomposing to promote the multiplication of micro-organisms that the fish feed on. The fish come in great numbers to these traps, a sort of gigantic creel. The branches offer an ideal place for reproduction and spawning because they allow the fish to dry. A few weeks after the installation of the acadjas, most of the fishermen encircle their parks with nets assembled for the circumstance in order to reduce the cases of escape of the trapped fish during their movements in particular when the density is strong.Harvesting is done once or twice a year. Exploited in the short term after 2 to 3 months, the acadja simply plays the role of a fish trap and therefore a fishing device. On the other hand, when it is exploited on a long term basis by cycle of 6 to 12 months, the acadja can be considered as an extensive aquaculture system.

The use of acadjas in Lake Nokoué has increased rapidly over the last two decades. In 1994, this fishing practice was used exclusively in the western/northwestern part of the lake around the village of Ganvié (Adite and Winemiller, 1997). Today, about 60% of the lake is occupied by acadjas (Mama et al., 2010). Approximately 200,000 tons of branches are introduced into the lake each year, and 40% of them sediment (Aglinglo et al., 1998).The acadjas provide fish with periphyton including bacteria, fungi, diatoms and filamentous algae as well as nematodes and crustaceans (Welcomme et al., 2005). In addition to providing supplemental food, the acadjas are constructed to provide a suitable environment for tilapia (*Tilapiine cichlid*) reproduction. The high productivity of Lake Nokoué compared to other West African coastal lakes can be explained by the presence of acadjas, which increase the abundance of juveniles (Villanueva et al., 2006), promote their growth and thus improve the artisanal fishery and the income of fishermen.

However, this practice also contributes to the reduction of biodiversity (Niyonkuru and Lalèyè 2010), the increase of turbidity and the progressive silting of the lake (Mama, 2010). Of the annual average of 200,000 tons of wood imported into the lake for the manufacture of acadjas, approximately 40% remains after harvesting and settles to the bottom of the lake. In addition, the practice of acadja fishing may affect hydrodynamic circulation and nutrient concentration in the lake, although this has not yet been quantified. Negusse and Bowen (2010) estimated that decomposition of acadjas would contribute over 35 tons per year of nitrogen and about 1 ton per year of phosphorus, contributing to eutrophication of the lake, along with sewage discharge. The presence of acadjas is also conducive to the retention and expansion of water hyacinth (Djihouessi et al., 2018).

The acadjas and the water hyacinth actively participate in the eutrophication of the lake.

Plate 2. Natural environment of Lake Nokoué during the high water period

3.1.2. Health consequences of these environmental problems

According to statistics published by the ministry of health for the year 2021, the main pathologies, reasons for consultation at the national level, are malaria (44.6%), acute respiratory diseases (12.9%) and gastrointestinal diseases (5.5%). according to information received from health workers in Ganvié, the same trio is in the lead. this is not surprising, since the environment and health are so closely linked.

Table 2. Distribution of pathologies encountered in all outpatients

Affection	Masculin		Féminin		Total	
	Nbre de cas	%	Nbre de cas	%	Nbre de cas	%
Paludisme	1 437 551	44,9	1 118 530	44,3	2 556 081	44,6
Infections respiratoires aigües	390 374	12,2	348 463	13,8	738 837	12,9
Autres affections gastro-intestinales	181 044	5,7	135 544	5,4	316 588	5,5
Traumatismes	80 214	2,5	128 301	5,1	208 515	3,6
Diarrhées	69 170	2,2	58 769	2,3	127 939	2,2
Anémie	58 598	1,8	43 345	1,7	101 943	1,8
Hypertension artérielle	46 289	1,4	30 750	1,2	77 039	1,3
Douleurs abdominales basses	64 520	2,0	10 764	0,4	75 284	1,3
Autres affections dermatologiques	32 936	1,0	32 863	1,3	65 799	1,1
Affections ostéoarticulaires	21 996	0,7	18 029	0,7	40 025	0,7
Reste des affections	819 854	25,6	598 124	23,7	1 417 978	24,8
Total	**3 202 546**	**100,0**	**2 523 482**	**100,0**	**5 726 028**	**100,0**

Source : SGSI/DPP/MS, 2021

The environment is a major determinant of human health, through various factors: the quality of the environment (air, water, etc.), the nuisances that are conveyed (noise, insalubrity, pollutions, etc.), climatic variations, etc.

3.1.3. Environmental challenges in Ganvié and in Lake Nokoué

It appears that the lake is mainly contaminated by organic matter, nutrients and metals: all of these substances are mainly due to the strong presence of acadja and water hyacinth that settle on the bottom and degrade over time, as well as to the anthropic pressure exerted on

the lake, particularly with regard to the discharge of uncontaminated effluents and the abandonment of solid waste both in the lakeside city of Ganvié and off Lake Nokoué.

Plate 3. Wild dumps off Lake Nokoué

In these photos, we can see various types of waste deposited off Lake Nokoué in various places, which are invaded by the tops and drained into the lake.We also see toilets made of sheet metal by the riverside communities; these serve as frames for them to urinate and defecate directly in the lagoon, further polluting an already polluted lake. According toBéhanzin et al. (2020), the presence of large piles of garbage in the cities and on the banks of the lagoons results in visual pollution, the proliferation of disease vectors (mosquito larvae, mosquitoes, flies and microbes), air pollution due to foul-smelling fumes, the emission of greenhouse gases (CH4, CO2), and the pollution of the soil, the water table and surface water.

Based on the threats identified, various measures aimed at preserving, restoring and sustainably exploiting the ecosystem of the Lake Nokoué lagoon complex can be envisaged. These measures obviously cannot be limited to the perimeter of the lake village of Ganvié but must be applied to the entire lagoon complex and watersheds. Indeed, the "eutrophication" problem highlights the fundamental relationship between the watersheds and Lake Nokoué. This interrelationship shows how necessary it is to have an integrated management approach, allowing action on different aspects (agricultural, urban, environmental, etc.). Curative measures at the lagoon level (e.g. hyacinth collection, improvement of water circulation, dredging, etc.) will only be complementary to global actions at the watershed level.

In addition, the preservation of the environment must be seen by the populations as a prerequisite for the sustainable management of the heritage and associated activities. It is essential to raise awareness and to involve local populations in a participatory management approach. The scientific monitoring of the evolution of the lagoon complex (physico-chemical and biological indicators) will also make it possible to verify the relevance of the development and management choices made and to readjust certain recommendations if necessary. It is also essential, before establishing a management plan, to prioritize the various sources of input and contamination in order to identify the priority actions to be implemented for the preservation of the lagoon complex.

The challenge is to sustainably preserve this site whose biological, cultural and landscape interests make it a major asset for the promotion of reasoned ecotourism and the development of educational projects to raise awareness of the environment and heritage. The local planning and development approaches will have to allow for a better positioning of this lagoon complex in the structuring elements of the territory both in terms of natural spaces and in the major cultural poles of the territory. The reconquest of the qualitý of the waters and of the biodiversity is thus the sine qua none condition to ensure the perennialitý of the halieutic and tourist economic activitý of Lake Nokoué and hope in the future to promote recreational activities there.

3.1.4. Actions for the sustainable development of Ganvié

Several development initiatives have been identified, the most prominent of which are:

- The **water hyacinth valorization project through composting and basketry** (PROJEC) implemented from 2013 to 2015 by ACED and its partner Gevalor in the commune of Sô-Ava, with the financial support of the Small Initiatives Program (PPI) of the French Global Environment Fund,The objective of the project is to contribute to the reduction of greenhouse gas emissions and the sustainable protection of biodiversity while impacting the livelihoods of the people through improved income. The project allows the transformation of water hyacinth into compost, used by market gardeners to fertilize their fields and increase their yields and income, and the transformation of water hyacinth into basketry products by women who earn after-sales income.

- Since 2019, the Beninese government has set itself the mission of "**reinventing the lake city of Ganvié**", through an ambitious program of preservation, renovation and development of the infrastructure of the said city. Accompanied by the French Development Agency (AFD), the project aims to improve the living conditions of the populations of the precarious neighborhoods, to encourage the development and diversification of resources from Lake Nokoué, while limiting pollution and negative impacts on the lake biotope. At the same time, the action also allows to improve the accessibility and the infrastructures available on site.

3.2 DISCUSSIONS

Lake Nokoué is under increasing anthropic pressure: growing urbanization, rainwater runoff and discharges from 16 urban collectors directly into the lake and the Cotonou channel, discharges from lake villages without a waste management and sewage treatment system, intensification of motorboating, illegal gasoline trafficking, intensive fishing for acadjas, intensification of agricultural areas in the watersheds, etc. This accelerated development, often anarchic and badly managed, has multiple serious consequences on the ecosystem, such as

- Heavy pollution with certain heavy metals and pesticides (and probably hydrocarbons) leading to bioaccumulation in the trophic chain and may give rise to significant public health problems;

- High concentrations of organic matter whose degradation increases eutrophication and decreases dissolved oxygen levels, which is harmful to organisms that are not tolerant of suboxic or anoxic conditions;

- A progressive filling of the lake linked to the various urban and peri-urban inputs, to the changes in land use that favor the scavenging of suspended matter towards the lake, and to the sedimentation of the detritus of the acadjas and the water hyacinth, etc. This progressive decrease of the water level in the lake can also be favored by the closing of the Cotonou channel induced in part by the natural dynamics of the sandy spit to the south of the channel, but also by the artificial filling of the Cotonou channel by the intensive dumps along its banks (notably by the market of Dantokpa)

Although not described in this study because it is not documented in the literature, Lake Nokoué must also suffer from significant macro- and micro-waste contamination, especially plastic, directly related to the massive discharges into the Cotonou channel by the Dantokpa market and surrounding neighborhoods, urban collectors used as dumping grounds, or more directly by fishermen and lake villages. Similarly, a significant activity has developed around dyeing, particularly along the banks of the Cotonou channel. This artisanal activity is an additional source of pollution and discharges, without prior treatment, wastewater loaded with chemical substances such as dyes, solvents, and heavy metals. Finally, pollution with emerging contaminants (surfactants, drug and pharmaceutical residues, algal toxins, etc.) cannot be ruled out but remains to be documented.

In a context of climate disruption and global change, the lagoon complex is also subject to a set of external factors that will necessarily affect its dynamics and ecosystem:

- Atmospheric temperatures in Benin have increased by 1.6°C between 1950 and 2010 (Amoussou et al., 2016) and are expected to continue to increase by more than 1°C by 2050 (Boko et al., 2012). This phenomenon could lead to an intensification of evaporation and evapotranspiration from the vegetation cover, producing an imbalance in the water balance and leading to an increased need for irrigation. This would reduce freshwater inflow to the lagoon complex and decrease the water level of the lake. On the other hand, increased evaporation from the lake in the future could also lead to hyper-salination during the flood period. In addition, the increase in temperature would further limit the dissolution of oxygen in the water, thus favoring anoxic events and the potential development of particular bacteria, some of which may emit methane, toxins or be responsible for fatal pathologies. Anoxic outbreaks can produce hydrogen sulfide, which is extremely toxic to animals and plants in the area.
- Over the past 50 years, average rainfall in Benin has tended to decrease, but future projections do not indicate clear variations other than a shift and decrease in the rainy season and an intensification of rainfall abatement (Amoussou et al., 2016; Boko et al., 2012). This leads to increased risks of point flooding, much more pronounced soil leaching, and thus a greater input of suspended matter and nutrients (nitrogen, phosphorus), further promoting lake filling and eutrophication.
- The sea level in the Gulf of Guinea is rising at a rate of 3 mm/year and coastal erosion and surge phenomena are likely to be more frequent. These phenomena, of marine origin, inevitably modify the barrier beach and the coastal ocean dynamics, which could modify the exchange of salt and polluting particles between the lagoon complex and the coastal ocean.

Due to the interactions between surface water and groundwater, it is important to note that the modification of the dynamics, salinity and contamination of Lake Nokoué, necessarily impacts the underlying aquifer that supplies drinking water to the cities of Cotonou and Abomey Calavi (Godomey wellfield) and Porto-Novo (wellfield located southwest of the city). If groundwater contamination is already observed (Dovonou et al., 2012; 2015) it will most certainly be increased in the future which will have a direct impact on the management of water resources for local populations.

4. CONCLUSION

In conclusion, the lacustrian city of Ganvié is facing a multitude of environmental challenges as it strives to develop and modernize. While the city has a unique and fascinating history, its future sustainability is uncertain as it contends with issues such as deforestation, pollution, and climate change. However, through a comprehensive literature review, we have identified several potential solutions and best practices that can help guide the city towards a more sustainable and resilient future. By prioritizing environmental protection and embracing innovative technologies and approaches, Ganvié can continue to thrive while also preserving its natural resources for generations to come. Ultimately, the success of Ganvié's development will depend on a collaborative effort between government, community leaders, and the broader international community, all working together towards a common goal of building a sustainable and thriving city on the water.

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