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Potentialities and constraints of fish farming in the northern Benin water reservoirs: What are the challenges?

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Abstract
Water reservoirs constitute a high potential for aquaculture promotion in Benin. Physical and chemical quality of their water and the presence of fish with high fish farming potential in their biodiversity reinforce this assertion. Main constraints limiting the development of fish aquaculture in northern Benin water reservoirs are (i) threats of agricultural pesticides that contaminate water reservoirs, act on the immunity of fish, their health status and cause an alteration of their sanitary quality, and (ii) lack of zootechnical standards adapted to this ecotoxicological context. In order to improve quantitatively and qualitatively fish production in these water reservoirs, it is of paramount importance that investigations be made on the fish farming systems that minimize the exposure of fish to pesticides and on the possibilities of decontamination of these fish. This will enable the satisfaction of the existing large internal market and ensure food security for the population.

Keywords: Water reservoirs, northern Benin, pesticides, fish farming, farming system

1. Introduction
In Benin, hydrographic network consisting of five river basins [1] is supplemented by numerous water reservoirs obtained by improving storage capacity of a natural bowl [2]. Mostly known as agropastoral water reservoirs, they were built massively in the 70s and 80s to remedy the water deficit caused by the severe drought in the West Africa countries, particularly in Benin, Togo, Côte d'Ivoire and Burkina Faso [3-5]. Over dug ponds and dams (Figure 1), a number of available water reservoirs in the countries is nearly 250 [1]. The four departments of the north part and that of the "Collines» in the central part of Benin contain respectively 86% and 11.2% of this total number of water reservoirs [1], the rest being in the southern Benin. Due to a low availability of halieutic products in the northern Benin, promotion and development fish farming activities in these water reservoirs has become a national and municipal priority. This results in the sporadic stocking of fish fry directly in open water [6] to increase the fishers' catches. Therefore, consensus is clearly established that these hydraulic structures, with a water capacity of between 10,000 and 1,650,000 m^3 [7], are now important resources whose aquaculture valorization can participate in improvement of fishery production level in Benin, as is the case in Côte d'Ivoire. In Côte d'Ivoire, dams located at the northern region contribute to between 16 and 46% of the national freshwater fish production [8] and generate at least 540 million CFA francs per year [9]. In order to mitigate the challenges of the valorization of aquaculture potential of these numerous Benin water reservoirs, the present review paper proposes to analyze the potentialities and constraints related to the development of fish farming in these environments.

2. Water quality of northern Benin water reservoirs
Table 1 presents mean values of physical and chemical quality parameters of water in the northern Benin reservoirs. According to [10] they are within tolerable ranges for tropical freshwater fish. However, nitrate levels are well above the favorable limit of 4 $mg.l^{-1}$ in fish farming, according to [11]. These high nitrate values are as a result of water reservoirs contamination by mineral fertilizers used in agriculture. Also, depth of the water reservoirs is favorable for fish farming in cages and pens. Indeed, [12, 13] recommend a depth of at least3 m for cages and 1.2 m for pens.

Fig 1: Differences between dam (A) and over dug pond (B) Sources: Google Earth & Bing Maps; Legend: 1 = bowl; 2 = dike and 3 = spillway (artificial channel in A or natural channel in B)

In addition, water and sediments (Table 2) of the water reservoirs are contaminated by agricultural pesticides. Besides the pyrethroids and organophosphorus compounds that are currently authorized in agriculture in Benin, organochlorine molecules banned since 2009 in Benin [14] are recently detected and quantified in water reservoirs. This is due not only to the sad reality that farmers continue to fraudulently use organochlorine insecticides [15-18] but also by their persistence in the environment [19]. It is important to remark that concentrations are very high as well as the order of milligram in the works as reported by [20]. This noticeable difference from other authors is related to the fact that, to assess the contribution of runoff to the pollution of reservoirs, samples were taken just after periods of heavy rainfall following pesticide applications in the fields. Overall, sediments of water reservoirs are more contaminated compared to water, with the exception of acetamiprid. Its low concentration in sediments is linked to the fact that it has a low organic carbon-water partition coefficient (Koc = 200) compared to organochlorines (Koc including 1888 and 151000) and organophosphorus compounds (Koc = 5509 for chlorpyrifos) [20, 21]. Maximum residue limits (MRL) of pesticides adequate for water and sediment quality for aquatic life are non-existent [22]. However, it should be noted that the concentration of each pesticide molecule in water is above the MRL (0.1 µg. l^{-1}) defined for drinking water [23], with the exception of organochlorines o, p'-DDD and p, p'-DDD. Furthermore, at the microbiological level, water reservoirs in Benin are contaminated by pathogenic bacteria including total coliforms, *Escherichia coli*, *Clostridium* spores, *Enterococcus feacalis*, *Salmonella typhi*, *Salmonella typhimurium*, *Salmonella enteritidis* and *Campylobacter jejuni* [24, 25].

Table 1: Physical and chemical parameters of water in Benin reservoirs

Parameters	Values (minimum-maximum)	References
T (°C)	23.5-26.1	[26]
	27.5-30.75	[27]
	29.9-31.4	[28]
pH	5.85-6.79	[26]
	8.43-9.3	[27]
	7.2-8.4	[28]
Transparency (cm)	26.2-55	[26]
	9.6-67.2	[28]
	15.5-52.5	[27]
Depth (cm)	4.2-7.5	[26]
Dissolved oxygen (mg. l^{-1})	1.23-2.16	[28]
Conductivity (µS. cm^{-1})	41 - 109.5	[27]
Total dissolved solids (mg. l^{-1})	20-54	
Total hardness (mg. l^{-1})	3.07-4.75	[26]
Carbonate hardness (mg. l^{-1})	0.21-5.45	
Nitrate (mg. l^{-1})	5.95-12.75	
Nitrite (mg. l^{-1})	0.18-0.40	
Phosphate (mg. l^{-1})	0.15-0.39	

Table 2: Pesticide residues identified and quantified in water and sediments of the Benin reservoirs

Families	Molecules	Values (minimum- maximum)	References
Water (µg. l^{-1})			
Organochlorines	p, p'-DDT	0.065-0.105	[29]
	o, p'-DDE	0.089-0.176	
	p, p'-DDE	0.074-0.178	[29]
		0.2	[21]
	o, p'-DDD	0.069-0.086	[29]
	p, p'-DDD	0.076-0.094	
	Endosulfan	2.92-13.83	[29]
		1	[20]
		0.2-0.9	[21]
	Heptaclor	0.45-1.444	[29]
	α -HCH	0.2-2.1	[21]
Neonicotinoids	Acetamiprid	0.2-7.7	[30]
		93-28.247 10^3	[20]
Organophosphorus	Chlorpyrifos	8-941	[20]
Pyrethroids	Deltamethrin	1-7	
Sediments (µg. kg^{-1})			
Organochlorines	Endosulfan	120-150	[31]
		0.6-101	[21]
	p,p'-DDE	0.7-2.8	[21]
	p,p'-DDT	1-1.8	
	p,p'-DDD + o,p'-DDT	1.6	
	δ - HCH	0.7-1.1	
	β + γ - HCH	3.6	
Neonicotinoids	Acetamiprid	0.1-479.8	[20]
		38-40	[31]
	Permethrin	0.8-11	[21]
	Deltamethrin	962-2022	[20]
	Cypermethrin	2099	
	Cyfluthrin	195-205	[31]
Organophosphorus	Chlorpyrifos	1-1.5	[21]
		58-208.8 10^3	[20]
	Profenofos	0.093-0.096	[31]
Pyrethroids	λ -cyhalothrin	0.8-8.8	[21]
		36-40	[31]

3. Biodiversity in northern Benin water reservoirs

Biological diversity in water reservoirs is still poorly studied in Benin. The study of [26] reports a rather poor zooplankton richness composed of Rotifers (*Brachionus calyciflorus* and *Brachionus* sp.), Cladocerans (*Moina micrura* and *Diaphanosoma* sp.) and Copepods (*Thermocyclops* sp. and *Mesocyclops* sp.). With regard to macroinvertebrates, [6, 32] have shown that benthic macrofauna of water reservoirs located at Banikoara and Kandi are largely composed of insects and a small proportion of Isopoda crustaceans. In this recorded entomological fauna, Diptera, Odonata and Heteroptera were the most represented taxa, while Coleoptera and Trichoptera had low representation. The synthesis of the works conducted by [24, 26, 28, 27, 6] in different water reservoirs in northern Benin reveals a fish richness of 39 distributed in 15 families (Table 3). This richness value is relatively low considering that the fresh and brackish waters of Benin have up to 234 fish species [33]. Nevertheless, it is close to that (between 12 and 36) reported by [9] in the small dams of northern at Côte d'Ivoire. However, this fish richness is low compared to 52 species which are found in water reservoirs in Burkina Faso [34]. In the ichthyofauna of Benin water reservoirs, *Oreochromis niloticus* and *Clarias gariepinus*, species with strong aquaculture performance are among the three species having an occurrence of 1 (Table 3). Crocodiles are also found in some water reservoirs [35, 26, 28, 27]. According to [35], two crocodile species namely *Crocodylus suchus* and *Osteolaemus tetraspis* are found in the water reservoirs of Nikki. Other wildlife species including snakes, tortures, bivalve molluscs and lizards also occupy the water reservoirs in northern Benin [28]. According to [35, 36] northern Benin water reservoirs contain ten macrophyte species which are *Eichhornia crassipes*, *Nymphaea lotus*, *Ceratophyllum demersum*, *Echinochloa pyramidalis*, *Pistia stratiotes*, *Nelumbo nucifera*, *Marsilea quadrifolia*, *Dulichium arundinaceum*, *Myriophyllum spicatum*, and *Ludwigia abyssinica*.

Table 3: Ichtyofauna of the water reservoirs in Benin

Families	Fish species	Occurrence *
Alestidae	*Brycinus longipinnis* (Günther, 1864)	0.6
	Brycinus nurse (Rüppell, 1832)	0.2
	Hydrocinus vittatus (Castelnau, 1861)	0.2
	Micralestes occidentalis (Günther, 1899)	0.2
	Micralestes pabrensis (Roman, 1966)	0.2
Anabantidae	*Ctenopoma petherici* Günther, 1864	0.4
Centropromidae	*Lates niloticus* (Linnaeus, 1762)	0.4
Channidae	*Parachanna obscura* (Günther, 1861)	0.4
Cichlidae	*Hemichromis bimaculatus* Gill, 1862	0.2
	Oreochromis niloticus (Linnaeus, 1758)	1
	Sarotherodon galilaeus (Linnaeus, 1758)	0.4
	Coptodon guineensis (Günther, 1862)	0.6
	Tilapia mariae Boulenger, 1899	0.2
	Tilapia zillii (Gervais, 1948)	0.2
Clariidae	*Clarias anguillaris* (Linnaeus, 1758)	0.2
	Clarias gariepinus (Burchell, 1822),	1
	Clarias ebriensis Pellegrin, 1920	0.2
	Heterobranchus longifilis Valenciennes, 1840	0.4
Claroteidae	*Chrysichthys nigrodigitatus* (Lacépède, 1803)	0.4
	Chrysichthys auratus (Geoffroy Saint-Hilaire, 1809)	0.4
Cyprinidae	*Barbus baudoni* Boulenger, 1918	0.2
	Barbus callipterus Boulenger, 1907	0.2
	Barbus macinencis Daget, 1954	0.2
	Barbus macrops Boulenger, 1911	0.4
	Barbus nigeriensis Boulenger, 1902	0.2
	Labeo parvus Boulenger, 1902	0.2
	Labeo senegalensis Valenciennes, 1842	0.4
	Raiamas senegalensis Steindachner, 1870	0.2
Hepsetidae	*Hepsetus odoe* (Bloch, 1794)	0.6
Malapteruridae	*Malapterurus electricus* (Gmelin, 1789)	0.4
Mormyridae	*Marcusenius senegalensis* (Steindachner, 1870)	0.2
	Mormyrus hasselquistii Valenciennees, 1846	0.2
	Mormyrus rume Valenciennes, 1846	0.4
	Mormyrus anguilloides Linnaeus, 1758	0.2
Osteoglossidae	*Heterotis niloticus* (Cuvier, 1829)	0.4
Poecilliidae	*Micropanchax pfaffi* (Daget, 1954)	0.2
Protopteridae	*Protopterus annectens annectens* (Owen, 1839)	0.4
Schilbeidae	*Schilbe intermedius* Rüppell, 1832	1
	Shilbe mystus (Linnaeus, 1758)	0.2

* Occurrence = number of studies reporting the presence of the species / total number of studies used

4. Constraints of fish production in northern Benin water reservoirs

4.1 Technical and management constraints

From [35, 37, 26, 28, 27, 6, 1], several constraints can be identified. Technically, there is the lack of zootechnical reference for fish farming, insufficiency of fish fry and feed supply centers, filling of water reservoirs due to an erosion and the proliferation of aquatic plants in water surface. In Benin, water reservoirs are managed by the committees. These management bodies are not functional in the majority of cases. Management constraints include conflicts between different actors exploiting the water reservoirs and lack of awareness of some people who steal fish and fishing gears. Another main constraint is the presence of crocodiles in water reservoirs that consume fish, dig holes in dikes and threaten the activities of fishers.

4.2. Climate change and impact on water reservoirs

The direct impacts of climate change on aquaculture are diverse [38]. Factors that influences fish production in northern Benin water reservoirs are changes in temperature, precipitation, flood and drought. In fact, fish are poikilothermal animals and so, any change in the temperature of their living environment has a negative impact on their overall metabolism, growth rate and final yield [38]. In addition, hydrological regime of northern Benin water reservoirs depends mainly on rainfall [20], an important climatic variable. Another source of supply of water to reservoirs is groundwater, which is also directly related to the climate [39]. It is therefore clear that climate change will have an impact on the water levels in reservoirs as noted by [5] and [2]. Already, depending on the quantity of phreatic water and rainfall, some reservoirs dry up completely during the dry season. They are usually called temporary water reservoirs. Those that retain a residual volume of water until the next rainy season are referred to as permanent water reservoirs [26]. This drying period of water reservoirs may limit the practice of fish farming to a specific period during year.

4.3 Agricultural activities and impacts on water reservoirs

4.3.1 Phytosanitary practices and contamination of northern Benin water reservoirs

The northern part of Benin is about 73% of the national surface and constitutes the country's granary. Chemical pesticides including insecticides and herbicides are used to protect different crops, especially cotton [20, 15]. Insecticides

are mostly organophosphorus and pyrethroids, while herbicides are composed of glyphosate and atrazine [16, 15, 40, 17]. Producers use bad practices such as the application of unauthorized biocide products, field's cultivation close to water reservoirs, mismanagement of pesticide packaging and the unreasoned increase in doses and frequencies of pesticide application [16, 15, 17, 18]. Water reservoirs are thus exposed to the contamination risks by pesticides (Figure 2) through drift and runoff [20, 41]. There are also the risks associated with using fertilizers in the fields, because eutrophication can occur, a phenomenon that has serious consequences for fish [42].

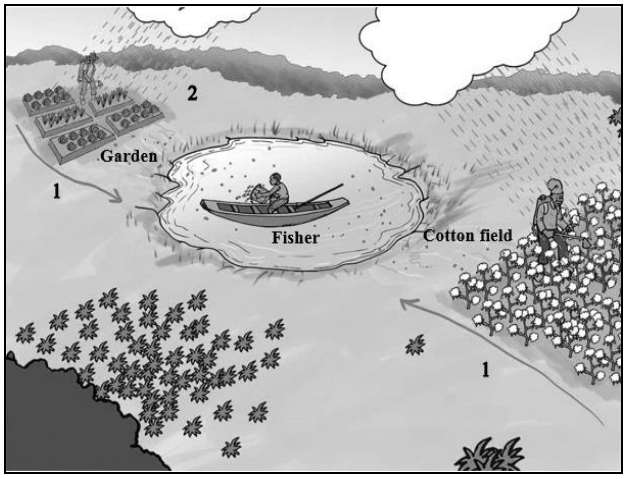

Fig 2: Contamination of water reservoirs used for fish production by pesticides used in cultivated areas; Legend: 1 = runoff carrying pesticides to the water reservoir; 2 = rain carrying pesticides from the drift to the water reservoir

4.3.2 Biological and zootechnical alterations in fish related to agricultural pesticides

In an aquatic environment, water-soluble molecules remain in the water column [43] and strongly threaten pelagic organisms while those hydrophobic, lipophilic (octanol-water partition coefficient, high Kow) are often persistently bound to sediments, decreasing their availability for pelagic organisms, but increasing the risk to benthic organisms [19]. According to [20], Environmental Risk Indices are relatively high (110-380) for the majority of molecules found in the water reservoir of Gambane with the exception of acetaprimid (4). In fish, fat-soluble molecules accumulate at increasing concentrations in the food chain [19]. They can alter many physiological functions in fish. Several authors have shown that agricultural pesticides disrupt hormonal regulation, negatively impact the hepatic system, energy budget, glycogen stores, growth and reproduction of exposed fish under laboratory conditions and wild fish captured in natural environments [44, 45, 29, 46, 47]. Similarly, pesticides are likely to alter nutrients fish body composition (proteins, lipids, carbohydrates and nucleic acids) that are used as energy sources in the detoxification and control of chemical stress [48]. In addition, fish exposure to pesticides can cause a dysfunction of their immune system. For this purpose [49, 50] reported in their literature review, an alteration of immune responses in fish exposed to agricultural pesticides. Unfortunately, this disruption of immune functions increases the sensitivity of fish to pathogens and diseases incidence [50].

4.3.3 Alteration of fish quality in northern Benin water reservoirs and health risks to consumers

Fish from water reservoirs play an important role in meeting the food needs at northern Benin [6]. The sanitary quality of these fish is altered by pesticide residues. Table 4 shows the pesticide residues levels in fish caught in the northern Benin water reservoirs. DDE and total endosulfan levels in fish are below 200 µg kg^{-1} set as maximum residue limits (MRL) in animal tissues [51]. It is the same trend for total DDT, which is very below to the MRL of 5000 µg kg^{-1} [51]. Also, chlorpyrifos concentration in fish is below to the MRL of 10 µg kg^{-1} [52]. Concerning the pyrethroids, all pesticide values in fish are lower than MRLs ranging from 10 to 30 µg kg^{-1} [53]. Based on these comparisons, levels of pesticides bioaccumulation by fish in Benin's water reservoirs are currently acceptable. In assessing the exposure of adult and children consumers of Nile tilapia and African catfish to DDT, endosulfan, chlorpyrifos, lambdacyhalothrin and beta-cyfluthrin, [21] reports that the estimated of daily pesticide consumption are lower than both the acceptable daily intake and the acute reference dose for each pesticide. Acute and chronic risks for fish consumers are currently almost non-existent for the different molecules taken individually.

Table 4: Pesticide residues in fish from the northern Benin water reservoirs

Families	Molecules	Values (minimum- maximum)	References
***Oreochromis niloticus* (µg. kg^{-1})**			
Organochlorines	p,p'-DDE	1-6	[21]
	p,p'-DDD + o,p'-DDT	2.1-3.2	
Organophosphorus	Chlorpyrifos	1.9-3.3	
Pyrethroids	λ -cyhalothrin	7.4-8.4	
	Permethrin	4.5	
	β -cyfluthrin	6.6-11	
***Clarias gariepinus* (µg. kg^{-1})**			
Organochlorines	α -endosulfan	2.4	[21]
	p,p'-DDE	1.7-36	

	p,p'-DDD + o,p'-DDT	8.7	
Organophosphorus	Chlorpyrifos	1.8-4.5	

4.3.4 Conclusion and challenges for improving fish production in northern Benin water reservoirs

Water reservoirs represent valuable resource for the development of fish aquaculture in Benin. Their water has physicochemical quality favorable to farming tropical freshwater fish like *C. gariepinus* and *O. niloticus* found in their fauna. To date, the aquaculture potential of these water reservoirs is still poorly exploited. The lack of biotechnical reference and threats related to agricultural pesticides that contaminate all matrices of water reservoirs and especially sediments are the first constraints to their recovery.

Since the pesticide impact on fish depends on their degree of exposure, it is essential for scientific investigations to be conducted on farming systems minimizing fish exposure to pesticides (cages for instance) especially during the rainy season which is the period of huge use of agricultural pesticides in northern Benin [29]. It is also of great importance that studies are made on the possibilities of fish decontamination by their transfer to pesticide free-water. Indeed, [54] reveal that fish eliminate more than half of benthiocarb and symetryn pesticides after their stay in clean water for 2-7 days. In addition to the removal of pollutant residues, this decontamination technique has the advantage of enhancing fish resistance to microbial aggression [50].

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