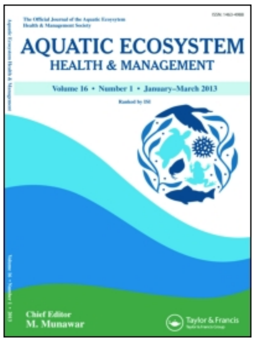

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Water quality as an indicator of the health status of agro-pastoral dams' ecosystems in Benin: An ecosystem services study

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Based on a study in three agro-pastoral dams in Nikki, Sakabansi and Fombawi in northern Benin, this article aims to characterize their physical, chemical and microbiological water quality. The ecosystem services framework underlies this article. Water of the three dams was sampled in the field and analysed at the laboratory. Means of variables were compared with standard values (norms) for drinking water set by both Benin and the World Health Organization. Agro-pastoral dams' water quality is problematic because of the significantly high levels of nitrite, nitrate, iron, and chemical oxygen demand. Water in these dams is unsuitable for both human and livestock consumption because it is contaminated with harmful bacteria including total Coliform, Escherichia coli*, spores of Clostridium,* Enterococcus feacalis, Salmonella typhi, Salmonella typhimurium, Salmonella enteritidis *and* Campylobacter jejuni. *This study concluded that one solution for maintaining agro-pastoral ecosystem health consisted of watershed management based on monitoring ecosystem services such as water quality.*

Keywords: pollution, Crocodiles, sustainable water resources management

Introduction

Human welfare depends either directly or indirectly on the services provided by ecosystems (van Oudenhoven et al., 2012). Aquatic ecosystems are vulnerable to anthropic and environmental changes, and many are severely degraded, starting with water quality (Brauman et al., 2007). This is particularly severe in public artificial lakes and rivers subject to intensive uses by multiple stakeholders who are involved in their management (Bell et al., 2013; Olden et al., 2014), leading to a decline in water quality and the depletion of aquatic biodiversity. Water quality is a function of the chemicals, pathogens,

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nutrients, salts, and sediments present in the water and an important attribute of hydrological services (Brauman et al., 2007). Water quality problems require urgent attention and action to sustain ecosystems and human life (WHO, 2011; Sandifer et al., 2015). Monitoring surface water quality is not a common practice in Benin (Hounsa et al., 2011).

The 1970 drought in Sahelian countries that caused water shortage and starvation compelled donors and governments to promote dams to water livestock and to enhance irrigated cereal production; in brief, to enhance food security (Venot et al., 2012). These dams have led to the extension of wetlands, creating permanent green pasture and favourable ecosystems for the expansion of wildlife such as Hippopotamus, Crocodile, Duck, Crane, Heron, Eagle, Cormorant, Pelican, and so forth. Therefore, dams also contribute to the maintenance of biodiversity (Bazin et al., 2011).

In Benin, 250 agro-pastoral dams (APDs) were constructed, and they have developed into multipurpose facilities: drinking water supply for humans, livestock watering place, fishing, vegetable, food and cotton production, cleaning, washing, swimming, cooking, small business water use, and house and road construction. They have become vital assets in local people's livelihood (Kpéra et al., 2012). As APDs are public property (Ostrom, 2011), each stakeholder tends to maximize the use of the dams, causing complaints from stakeholders about water pollution, predation of Crocodiles on valuable fish species, depletion of fishing yield, dyke damage by Crocodiles, conflicts between herders and farmers, conflicts between humans and Crocodiles, lack of maintenance of the APDs, and ignorance of wildlife conservation (Kpéra et al., 2012). Concerning the complaints of water pollution, several sources of bad water quality like agricultural runoff, dump runoff, and human and animal wastes were mentioned (Kpéra et al., 2012).

Several scholars have highlighted the importance of water quality for the health of freshwater ecosystems (Lu et al., 2015; Sandifer et al., 2015). Processes and functions such as groundwater quality, dehydration, global warming, aquatic and terrestrial ecotoxicity, acidification, and eutrophication can affect physical, chemical, and microbial water quality (Jeppesen et al., 2015). Through the lens of three agro-pastoral dams (Nikki, Sakabansi, and Fombawi) in Nikki District, northern Benin, the article addresses the characterization of APD water quality (physical, chemical, and microbiological composition).

Ecosystem services framework

A useful conceptual framework for environmental processes and the links between human activities and their impact on ecosystem functioning is provided by the ecosystem services (ES) framework (Bastian et al., 2013; Sandifer et al., 2015). The framework is presented in Figure 1. We address APD ecosystems and their boundaries, with specific reference to Nikki, Sakabansi and Fombawi.

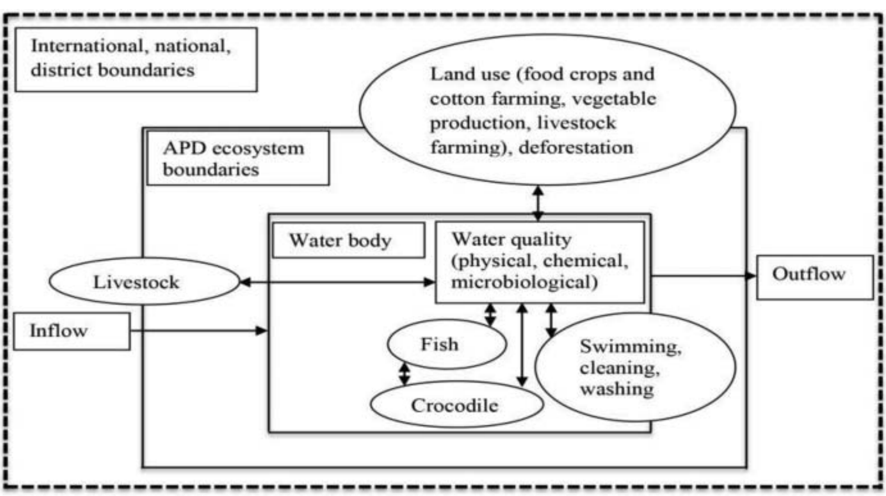

Figure 1. Ecosystem services and human use of the APD ecosystem.

Agro-pastoral dam ecosystems and boundaries

The Nikki, Sakabansi, and Fombawi APDs are fed, respectively, by the temporary rivers, which are under the influence of the attributes of the Oli sub-watershed (Brauman et al., 2007) that is part of the large Niger River watershed (Azonsi et al., 2008). Water originating from the rivers is drained into the dam basins during the rainy season and retained by the dyke, and excess water flows out of the dam into the river. Thus, an APD's ecosystem is the body of water and the surrounding watershed where communities of organisms are dependent on one another (MEA, 2005).

Watersheds in mainly dry areas are fertile agricultural areas from where nutrients, pesticides, and pathogens are transferred through runoff into rivers and APDs, affecting physical, chemical, and microbial water quality (Pimentel et al., 2004).

The sizes of the catchment basins for Nikki, Sakabansi and Fombawi are different (120 km^2, 20 km^2 and 2.4 km^2, respectively). As boundaries of the APD ecosystems, we considered the area located within a 10 km radius of the APD water body for Nikki and Sakabansi and 2 km for Fombawi, thereby staying within the watersheds and including diverse agricultural land uses, human settlements, and other ES that are likely to affect the APDs.

Ecosystem services provided by APD ecosystems

ES are manifold and tightly interlinked. They can be divided (MEA, 2005) into four categories: (i) provisioning services such as food, water, timber, and fibre; (ii) regulating services like biodiversity and services that affect climate, floods, diseases, wastes, and water quality; (iii) supporting services such as soil formation, photosynthesis, and nutrient cycling; (iv) cultural services that provide recreational, aesthetic, and spiritual benefits (Bastian et al., 2013). Evaluating knowledge about ES and human utilization of these services can inform management and policy decisions about ecosystems and their services.

The most important ES provided by the studied APDs include (Kpéra et al., 2012):

- Provisioning services: drinking water for humans and livestock, water for cleaning, washing, cooking, small business water use, house and road construction; food (fish, livestock, crops, and vegetables); timber (wood for cooking); and fibre (cotton).
- Regulating services: biodiversity of the APD ecosystem (Crocodiles, fish species richness and diversity) and services that affect water quality and diseases. Besides, several other species of wild animals occupy the dams, including snakes, Monitor Lizards, turtles and birds. Crocodiles appear to be the most impressive of all these animals in size, and people give them full attention. They occur in all the three dams but in different numbers.
- Supporting services: soil formation and nutrient cycling.
- Cultural services: recreation benefits (swimming, fishing) and spiritual benefits (Crocodiles considered as holy animals that provide welfare to their worshippers).

Materials and methods

Research setting

The study was carried out in the APDs of Nikki, Sakabansi and Fombawi villages located in Nikki District, which lies in the Borgou Department in north-eastern Benin (Figure 2). Covering an area of 3,171 km^2 and lying between 9°56′ 2N and 3°12′ 16E, Nikki District is home to 20 APDs constructed by the national government as watering holes for livestock and for agricultural sector development. The climate of north-eastern Benin is of the Sudanese type with two seasons: a wet season from May to October and a dry season from December to April.

The features of Nikki, Sakabansi and Fombawi agro-pastoral dams (Kpéra et al., 2012) are presented in Table 1.

Especially in Fombawi, there are traditional rules that support living peacefully together with the Crocodiles, based on the belief that Crocodiles are sacred creatures. This belief gives confidence to local people to swim in APDs without worries (Kpéra et al., 2014).

Data collection

Water quality: Physical, chemical and microbiological parameters

Water from the three APDs was sampled three times in 2012 for both physical and chemical parameters and microbiological parameters: in June, representing the end of the dry season; in

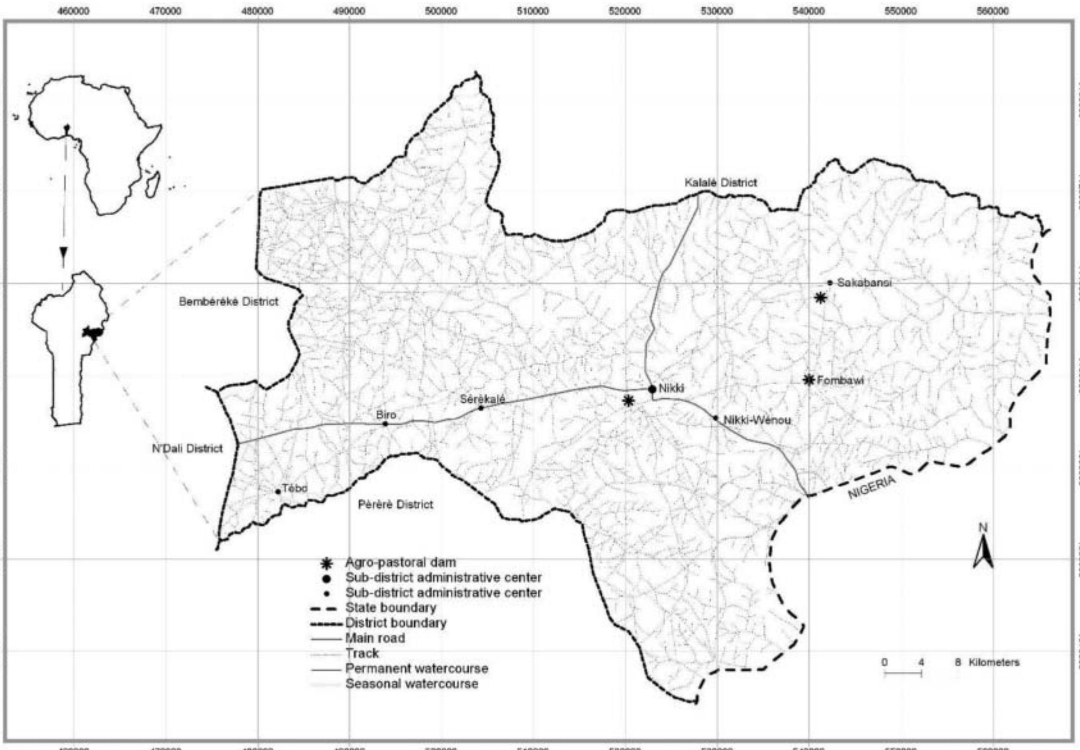

Figure 2. Location of Nikki, Sakabansi and Fombawi agro-pastoral dams (source: Kpéra, 2010).

September for the peak of the rainy season; and in December, representing the inter-season in northern Benin. The year 2012 was particularly characterized by a long dry season which extended to June instead of May. Physical and chemical parameters selected are among those suggested by WHO (2011) to assess water quality. These parameters include: temperature, pH, electrical conductivity (EC), nitrite (NO_2^-), nitrate (NO_3^-), ammonium (NH_4^+), phosphates (PO_4^{3-}), sulphates (SO_4^{2-}), chlorides (Cl^-), bicarbonates (HCO_3^-), calcium (Ca^{2+}), magnesium (Mg^{2+}), total iron (Fe), chemical oxygen demand (COD), and total hardness. Temperature was identified using a thermometer

Table 1. Main features of the three cases: Nikki, Sakabansi and Fombawi agro-pastoral dams.

	Nikki	Sakabansi	Fombawi
Inhabitants	31,661	2,072	1,490
Year of construction	1972 and renovated in 1996	1985	1989
Watershed/sub-watershed	Niger/Oil	Niger/Oil	Niger/Oil
River	Sora	Samana	Kuena
Capacity (m^3)	257,000	200,000	170,000
Catchment basin (km^2)	120	20	2.4
Location of dam from the town/village (km)	2	3	0.3
Number of Crocodiles	<20	>100	>300
Fishing frequency	Daily	Yearly	Yearly

(OAKTON); EC using a conductivity meter (PIONEER 10); pH using pH meter (OAKTON); NO_2^-, NO_3^-, NH_4^+, PO_4^{3-}, SO_4^{2-}, Fe, COD by spectrophotometry (APHA, 1992), HCO_3^-, Cl^-, Ca^{2+}, Mg^{2+}, and hardness by titration (APHA, 1992).

As the APDs are used as drinking water by both humans and livestock, microbiological analyses were performed to detect total Coliform, *Escherichia coli*, spore of Clostridium, *Enterococcus feacalis, Salmonella typhi, Salmonella typhimurium, Salmonella enteritidis* and *Campylobacter jejuni* (WHO, 2011).

Water sampling was done at three main sites (up-stream, middle, and downstream) per dam and in each season, corresponding to nine measurements per dam during 2012. Water samplings upsteam, middle, and downstream were not made to see variations within the dams but to have a composite sample which is representative of each dam. Direct measurements were made in the field for parameters like temperature and pH and electrical conductivity of the water, and the other physical and chemical parameters were analysed in the laboratory Water samples (nine samples per dam) were collected in sterilized 2-litre bottles (Sharifinia et al., 2013) from each sampling site between 06.00 and 11.00 am. The samples were labelled, kept in an ice chest, and transported the same day to the water analysis laboratory at the Energy and Water Service of Borgou and Alibori Districts. Standard methods were used to analyse the water parameters (APHA, 1992, 1998).

To test the microbiological quality of the dam water, composite samples were collected in sterilized 1-litre bottles, labelled, kept in an ice chest, and transported the same day to the laboratory (Pradhananga et al., 2013). The total plate count was conducted by the pour plate technique on plate count agar (PCA) and by counting the developed colonies after incubation for 24 h at 37°C using standard methods (APHA, 1992, 1998). Colonies of total Coliform, *E. coli*, spore of Clostridium, and *E. faecalis* colonies were counted in 1 ml of water. The presence or the absence of *S. typhi*, S. *typhimurium, C. jejuni* and *S. enteritidis* were checked in the same quantity of water (APHA, 1992, 1998).

Data analysis

A full 3 × 3 factorial experiment was conducted and carried out with three repeated measures. Factors and levels were: APD with three levels (Nikki, Sakabansi, and Fombawi) and season with three levels (peak of dry season corresponding to June 2012, peak of rainy season corresponding to September 2012, and inter-season corresponding to December 2012).

Variability in the physical and chemical water parameters (variables) of the three APDs was analysed using analysis of variance (ANOVA) with repeated measures (Crowder and Hand, 1990) using SAS/STAT®9.2 software. We analysed season and APD effects and the effect of the interaction between dam and season using the Student-Newman-Keuls (SNK) test.

Pairwise correlation between the physical and chemical parameters was investigated disregarding dam and season effect and their interaction. The correlation coefficient (r) at the 5% level of significance was determined with R 3.2 software.

Finally, we compared the means of variables with standard values (norms) for drinking water set by both Benin (Anonymous, 2001) and the World Health Organization (WHO, 2011). The difference between these two norms resides in the fact that the WHO standard is regularly updated. Firstly, normality was checked using a Shapiro-Wilk normality test. In the case of normality, Student's t-test was used; otherwise we performed a Wilcox.test (Glèlè Kakaï et al., 2006; Ruxton and Neuhäuser, 2010) using R 3.2 software. The study was searching for probable water pollution. Thus, we were interested in an effect in one direction because water quality becomes problematic when the mean values exceed the norms (average or optimal value) for all the parameters except those with an optimal range (pH and hardness; WHO, 2011). Thus, we used one-tailed hypothesis testing (Ruxton and Neuhäuser, 2010). For this test, the null hypothesis was that there is no difference between the means and the norms, and the alternate hypothesis was that means are greater than norms for all the variables except pH and hardness. For the variables pH and hardness, hypothesis testing checked the same null hypothesis but with both alternative hypothesises (mean less than norm for the lowest norm and mean greater than norm for the highest). The variables temperature and bicarbonate do not have standard values set by either Benin or WHO; therefore, they were excluded from the conformity test.

Results

Variation in physical and chemical water parameters

Results of the ANOVA with repeated measures (Table 2) indicate that the factor dam significantly affects all the parameters except temperature, nitrate, and magnesium. The factor season highly affects ($p < 0.001$) all the physical and chemical parameters. The interaction dam × season is non-significant for the variable temperature, significant for nitrite ($p < 0.01$) and nitrate ($p < 0.05$), and highly significant ($p < 0.001$) for the other physical and chemical parameters (Table 2), meaning that the season effect on temperature does not depend on the dam effect.

Furthermore, for the three dams, the means of physical and chemical parameters are significantly different during the three seasons as established by the Student-Newman-Keuls test ($p < 0.05$).

In Nikki dam in June, conductivity, carbonate, chlorides, calcium, and hardness showed high values. In September, temperature, nitrite, ammonium, phosphates, sulphates, iron, COD, and magnesium also showed the same trend, whereas only pH and nitrate were high in December.

In Sakabansi in June, pH, ammonium, and chlorides were at their highest values, whereas conductivity, COD, magnesium, and hardness showed this trend in December.

In Fombawi in June, all parameters, except temperature, nitrite, nitrate, phosphate, sulphates, and magnesium, showed a high value. In September, only pH, nitrite, and sulphates showed this trend, whereas in December, phosphates concentration in the dam was high. Whatever the APD, the levels of pH, nitrite, and sulphates were at their highest values in September, whereas the concentration of chlorides was high in June. The recorded physical and chemical data in Nikki, Sakabansi and Fombawi is presented in the Appendix (available in the online supplementary information).

Correlation between physical and chemical parameters

In Figure 3, only significant ($p < 0.05$) correlations are shown, and correlations above 70% are discussed. The blank cells mean that the correlations are not significant ($p > 0.05$).

First, for the physical parameters (temperature, COD, pH, conductivity and hardness), temperature is positively associated with nitrate, but negatively with COD, conductivity and chlorides. In addition

Table 2. F-values and probability levels from the analysis of variance with repeated measures on the physical and chemical water parameters.

	Dam		Season		Dam × Season	
Parameters	df	F-values	df	F-values	df	F-values
T	2	0.38 ns	2	1,486.67***	4	2.79 ns
EC	2	987.11***	2	3,064.71***	4	879.58***
Ph	2	29.32***	2	47.24***	4	46.18***
NO_2^-	2	25.26**	2	99.33***	4	6.52**
NO_3^-	2	1.90 ns	2	39.13***	4	4.43*
NH_4^+	2	72.10***	2	154.89***	4	109.96***
PO_4	2	380.41***	2	147.88***	4	262.18***
SO_4^{2-}	2	14.29**	2	76.55***	4	14.36***
Fe	2	20.28**	2	16.04***	4	27.30***
COD	2	177.46***	2	400.96***	4	103.84***
HCO_3^-	2	8.80*	2	54.87***	4	15.04***
Cl^-	2	40.09***	2	168.66***	4	11.33***
Ca^{2+}	2	182.65***	2	315.73***	4	203.78***
Mg^{2+}	2	3.03 ns	2	61.45***	4	47.10***
Hardness	2	106.35***	2	48.71***	4	109.23***

df = Degree of freedom, F = Fisher. *, ** and *** indicate significant effects $p < 0.05$, $p < 0.01$ and $p < 0.001$, respectively.

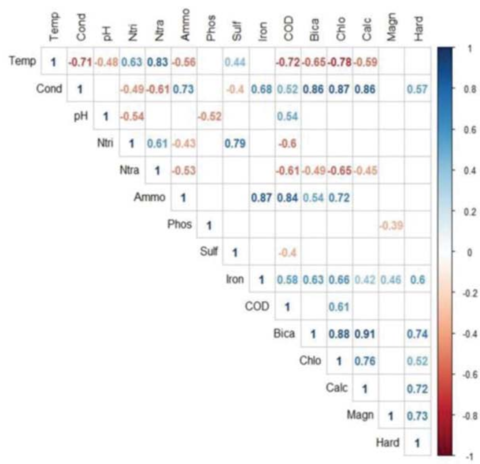

Figure 3. Correlation between physical and chemical water parameters. The darker hues indicate where the correlation is strong. Only significant correlations ($p < 0.05$) are presented. Temp = temperature; Ntra = nitrate; Ntri = nitrite; Phos = phosphates; Sulf = sulfates; COD = chemical oxygen demand; Ammo = ammonium; Bica = bicarbonates; Calc = calcium; Cond = electrical conductivity; Chlo = chlorides; Magn = magnesium; Hard = hardness.

to the negative correlation with temperature, COD is positively associated with ammonium. pH has no strong linkage with the other parameters; meanwhile conductivity has a positive association with ammonium, bicarbonates, chlorides and calcium and a negative association with temperature. Hardness is correlated with bicarbonates, calcium and magnesium.

For the chemical parameters (nitrite, nitrate, ammonium, phosphates, sulfates, iron, bicarbonates, chlorides, calcium and magnesium), nitrite has a positive link with sulfates and represents the single association of sulfates; similar to nitrate linking with temperature. Phosphates have no link with the other parameters. Ammonium is linked positively with conductivity, iron, COD and chlorides. Bicarbonates are positively correlated to conductivity, chlorides, calcium, and hardness. Chlorides are linked positively with conductivity, ammonium, bicarbonates, and calcium but are negatively associated with temperature.

Conformity of physical and chemical parameters to Benin and WHO norms

Overall, two physical parameters (pH and COD) and three chemical parameters (nitrite, nitrate, and iron) in the three APDs were found to exceed the norms (Table 3). Nitrite, nitrate, iron and COD exceeded norms, whereas pH was less than the lowest limit set for drinking water.

Iron recorded a significantly high concentration ($p < 0.01$) everywhere in all seasons except in December in Nikki. Nitrite recorded a significantly ($p < 0.01$) high concentration in Nikki and Fombawi in September, showing that it originated from runoff. Nitrate exceeded norms in the three APDs Nikki and Sakabansi ($p < 0.05$) and more significantly ($p < 0.01$) in Fombawi. As for COD, the high records were observed in the dry season in Sakabansi and Fombawi. Conversely, in Fombawi, water was too acid ($p < 0.05$) during the inter-season.

To sum up, in the three dams, five parameters seem problematic: four (nitrite, nitrate, iron, and COD) were higher than the norm, whereas pH was below the norm set for drinking.

Microbiological quality of APDs

The results of the microbiological analysis of water from the three APDs during the three periods of the year are presented in Table 4.

Total Coliform and spore of Clostridium scores are very high everywhere and in all seasons. Next come *E. coli* and *E. feacalis*. *S. typhimurium* is never found to be present. *S. typhi* is only present in September, in Sakabansi and Fombawi. September is characterized by a high presence of bacteria colonies in the three APDs. Of the three APDs, Sakabansi appears less affected, whereas Nikki seems the most infested. To conform with Benin and WHO guidelines, drinking water should not contain the tested bacteria.

Discussion

Water quality and its effect on the APD ecosystem

The study was carried out in three APDs in northern Benin, West Africa. The results show that nitrite, nitrate, iron, and COD exceeded the norms set for drinking water. The high levels of nitrite everywhere during the rainy season and of nitrate in Nikki and Fombawi APDs are probably a result of agricultural runoff, refuse dump runoff, or contamination with human and animal wastes (WHO, 2012). In Nikki (with a high population

Table 3. T-values/v-values and probability levels from the conformity test of the physical and chemical water parameters to Benin and WHO norms in Nikki, Sakabansi and Fombawi.

		Nikki			Sakabansi			Fombawi		
Parameters	Norms (mg l^{-1})	June	Sept	Dec	June	Sept	Dec	June	Sept	Dec
pH	Benin (6.5–8.5)	6 ns	6.42 ns	6 ns	7.46 ns	6 ns	17.32 ns	11.72 ns	6 ns	−5.20 ns
		0 ns	−16.25 ns	0 ns	0.57 ns	0 ns	−17.32 ns	−10.96 ns	0 ns	−39.84 ns
	WHO (6.5–8.5)	6 ns	6.42 ns	6 ns	7.46 ns	6 ns	17.32 ns	11.72 ns	6 ns	−5.20 ns
		0 ns	−16.25 ns	0 ns	0.57 ns	0 ns	−17.32 ns	−10.96 ns	0 ns	−39.83 ns
NO_2^-	Benin (3.2)	−6.79	6.65**	−6.27 ns	0 ns	1.45 ns	0 ns	−20.16 ns	7.26**	0.42 ns
	WHO (3)	−3.30 ns	7.58**	−3.00 ns	0 ns	4.29 ns	−905.10 ns	−17.48 ns	8.29**	1.07 ns
NO_3^-	Benin (45)	−10.16 ns	2.12 ns	5.50*	−12.32 ns	4.30*	1.73 ns	−1.64 ns	29.44***	0.84 ns
	WHO (50)	−17.98 ns	0.59 ns	3.65*	−20.70 ns	1.77 ns	−0.39 ns	−2.70 ns	18.36**	−3.36 ns
Fe	Benin (0.3)	12.60**	78.53**	6 ns	7.85**	58.89***	16.44*	5.44*	20.03*	7.45**
COD	Benin (125)	−49.78 ns	−45.17 ns	−54.60 ns	9.35**	−18.72 ns	−19.39 ns	11.77**	−19.08 ns	−45.89 ns

*, **, *** significant effects at $p < 0.05$, $p < 1.01$ and $p < 0.001$, respectively; ns = not significant; significant effects are bold; Sept = September; Dec = December; t-value (t): from Student's t-test; Wilcoxon-value (v): from Wilcox test.

Table 4. Microbiological analysis of water from Nikki, Sakabansi and Fombawi APDs per period.

	Nikki			Sakabansi			Fombawi		
Bacteria	June	Sept	Dec	June	Sept	Dec	June	Sept	Dec
Total Coliform	28	CL	1,056	163	456	488	470	496	380
Escherichia coli	0	248	0	13	4	0	70	24	0
Spore of Clostridium	24	CL	42	60	4	8	76	CL	6
Enterococcus faecalis	0	28	4	0	0	8	8	4	0
Salmonella typhi	−	−	−	−	+	−	−	+	−
Salmonella typhimurium	−	−	−	−	−	−	−	−	−
Salmonella enteritidis	+	+	+	−	−	−	+	−	−
Campylobacter jejuni	+	−	−	−	−	−	−	−	+

Number represent the counting of the developed colonies after incubation for 24 h. − = absence; + = presence; CL – countless (so many as to be impossible to count); Sept = September; Dec = December.

and resultant sewage), food cropping and cotton farming (around the dam) and vegetable production (up-stream the dam) are characterized by frequent use of NPK fertilizers rather than organic fertilizers. Although phosphates showed a high value during the rainy season, the level did not exceed norms, indicating that waste, manure, effluent, and runoff may be mainly responsible for high nitrite and nitrate levels through nitrogen, thus contributing to eutrophication causing the invasion of the APDs by floating grasses (personal observation; Kpieta and Laari, 2014).

The results show that substantially high values for iron were recorded in the three APDs. These high records in the three APDs could emanate from the ferralitic nature of the Nikki District soils–which typically have a high iron content–resulting from dissolved iron from the soil and rock formations drained by runoff (Ngah and Nwankwoala, 2013). This could also be an indication that the APDs' watershed is being eroded by tillage, contributing to siltation in the dams. Studies revealed that for Okpara dam in Northern Benin–fed by the Ouémé River and whose watershed extends to Nikki District–very high iron levels were also recorded (30 to 50 mg l^{-1}; Tomètin et al., 2014).

Furthermore, COD exceeded norms during the dry season in Sakabansi and Fombawi, indicating higher concentration of biodegradable and non-biodegradable organic matter (Mirhossaini et al., 2010) in these two APDs; these may originate from agricultural runoff, effluent, and refuse dump runoff during the rainy season that are stored in the APDs which act as a sink during the dry season. On the assumption that the degradation of water quality in up-stream parts of a watershed can have effects on downstream users because of a continuum of users throughout a watershed, this suggests that water quality up-stream and downstream of the APDs should be monitored to better understand the functioning of the dams over seasons/years and as a sink.

The results show linkages between parameters (conductivity, ammonium, bicarbonates, chlorides, calcium, magnesium and total hardness) that are indicators of the hardness of the APD waters (Bhandari and Nayad, 2008). Furthermore, the high correlation coefficient between ammonium and hardness suggests that ammonium contributed to the hardness of the APDs' water. This is confirmed by the positive linkage between ammonium and conductivity and chlorides being indicators of water hardness. However, all these parameters including total hardness recorded normal levels in terms of WHO and Benin tolerable limits, leading to the conclusion that the APDs' waters are soft. This is why APD water is appreciated by users for washing and cleaning (personal observation).

APD infestation by *E. coli*, spore of Clostridium and *E. faecalis* almost always indicates recent faecal contamination (Kpieta and Laari, 2014), probably emanating in Nikki from an open dump, runoff from the town, effluent, and manure left by livestock, and in Sakabansi and Fombawi from runoff originating from the villages, bathing, washing, cleaning, and animal manure. For water to be considered as no risk to human health, the faecal coliform and *E. coli* counts 100 ml^{-1} should be zero (WHO, 2011). This suggests that research should be undertaken on the epidemiology of waterborne diseases that occur in the villages using the APDs.

Previous research noted the use of cotton pesticides in vegetable production – prohibited organochlorine pesticides: endosulfan (benzoepin), lindane (gamma-hexachlorocyclohexane), and DDT (dichlorodiphenyltrichloroethane)–around APDs (Kpéra et al., 2012). Such practices entail potential undesirable effects for APD ecosystem services and functions (MEA, 2005). Unfortunately, no research has yet been carried out to determine pesticide levels in APDs in Benin.

Finally, APD water quality may affect several regulating services such as soil structure and fertility conservation, soil quality improvement, water purification, efficient use of agronomic inputs, carbon sequestration, and water quality improvement through filtration and denaturation of pollutants (MEA, 2005), supporting services (nutrient cycling), and cultural services that provide recreation (safe swimming and bathing; Bastian et al., 2013).

Conclusions

Agro-pastoral dam ecosystems, by providing numerous services to their users, contribute directly or indirectly to the user's wellbeing. This first assessment of APDs' ecohealth status in Benin reveals that there is a significantly higher level of nitrite in the three APDs studied than permitted by the norms for drinking water; the same is true for nitrate in Nikki and Fombawi APDs. All the dams have too high a concentration of iron. In Sakabansi and Fombawi, chemical oxygen demand (COD) exceeds the Benin and WHO norms. Correlations between physical and chemical water parameters for hardness are significant. This, combined with the normal levels scored by these parameters, leads to the conclusion that the APDs' waters are soft. The presence in the APDs' waters of bacteria such as Coliforms, *E. faecalis, E. coli*, spore of Clostridium, *S. typhi* and *C. jejuni* classifies the dams' waters as unsuitable for human and livestock water consumption in accordance with the Benin and WHO guidelines. Therefore, current APD water quality may affect several ecosystem services: providing, regulating, supporting and cultural services.

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Supplemental material

Supplemental data for this article can be accessed on the publisher's website.

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