UNDERSTANDING COMPLEXITY IN MANAGING AGRO-PASTORAL DAMS ECOSYSTEM SERVICES IN NORTHERN BENIN

Gnanki Nathalie KPERA

Understanding complexity in managing agro-pastoral dams ecosystem services in Northern Benin

Gnanki Nathalie Kpéra

Thesis committee

Promotor

Prof. Dr M.N.C. Aarts

Personal chair at the Strategic Communication Group

Wageningen University

Co-promotors

Prof. Dr A.J. van der Zijpp

Emeritus Professor of Animal Production Systems

Wageningen University

Dr G.A. Mensah

Research Director, National Institute of Agricultural Research of Benin,

Abomey-Calavi, Benin

Prof. Dr C.R. Tossou

Professor of Agricultural Extension, University of Abomey-Calavi, Benin

Other members

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Dr D. Hounkonnou, the West African Rural Foundation, Benin

Dr A. van Paassen, Wageningen University

This research was conducted under the auspices of the graduate school of the Wageningen Institute of Animal Sciences (WIAS) and the Wageningen School of Social Sciences (WASS)

Understanding complexity in managing agro-pastoral dams ecosystem services in Northern Benin

Gnanki Nathalie Kpéra

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To

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Late Roger & Zénabou KPERA

Marie-Madeleine & Seidou MAMA SIKA

CONTENTS

CHAPTER 1

General introduction

Introduction

1.1 Relevance of agro-pastoral dams

Water is a vital asset. Today, access to clean water is no longer seen as a free commodity but as a limited natural resource, an economic good, and a human right (WCD, 2000). The persistent recurrence of drought and the increasing severity of its impacts call for water management approaches to reduce shortages in water supply systems, especially in the semi-arid tropics and subtropics (Falkenmark, 2013). The construction of dams in West Africa has been found to be a sound strategy to increase water storage capacities, regulate water flows, contribute to food security, increase livelihood resilience, and maintain or/and improve wetland ecosystem functions and services as important components to assist people to adapt to climate change (Sally et al., 2011; IUCN-PACO, 2012; de Fraiture et al., 2014).

West Africa is considered to be poorly supplied with water infrastructures (IUCN-PACO, 2012). In villages without easy access to water sources, local communities greatly benefit from dams' ecosystem services for many purposes including crop production, livestock watering, fisheries, domestic and small business water use, and handicraft activities (FAO, 2008; IUCN-PACO, 2012). Moreover, dams have led to the extension of wetlands, creating permanent green pasture and favourable ecosystems for the expansion of wildlife such as hippopotamus, Nile 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, agro-pastoral dams (APDs) attract several stakeholders – including crocodiles – who use the water for different purposes, creating conflicts among them about how to use and manage the APDs as well as causing environmental problems (Projet AGRE, 2004; Houngnihin, 2006; Capo-Chichi et al., 2009; Kpéra, 2009; Kpéra et al., 2012; Kpéra et al., 2014). Resolution of these conflicts requires a more refined understanding of the multi-stakeholder use and management of APDs.

1.2 Agro-pastoral dams: their distribution and importance for the Benin Government

The severe drought of 1970 which caused high mortality of ruminants (cattle, sheep, and goats) in northern Benin compelled the government of the Republic of Benin to promote APDs to water livestock and to boost livestock production (Bouraima, 2006). An APD

ecosystem is an aquatic ecosystem consisting of a water body with surrounding land used for a variety of functions. The dissemination of the 250 APDs over the country (Azonsi et al., 2008) depends on the need for water and the size and the distribution of livestock. The distribution of the APDs in the different departments of Benin is: Borgou: 85; Atacora: 58; Alibori: 57; Collines: 27; Donga: 14; Plateau: 4; Couffo: 3; Zou: 2; Mono: 0; Atlantique: 0; Littoral: 0; Ouémé: 0 (see Figure 1.1). The reservoir capacity of APDs constructed between 1970 and 1980 varied from 10,000 m^3 to 130,000 m^3 with an average capacity of 50,000 m^3 (Capo-Chichi et al., 2009). Since 1988, efforts have been oriented towards constructing APDs with large volumes (30,000 m^3-1,650,000 m^3) and multi-purpose uses (pastoral, agricultural, silvicultural, and piscicultural) (Capo-Chichi et al., 2009).

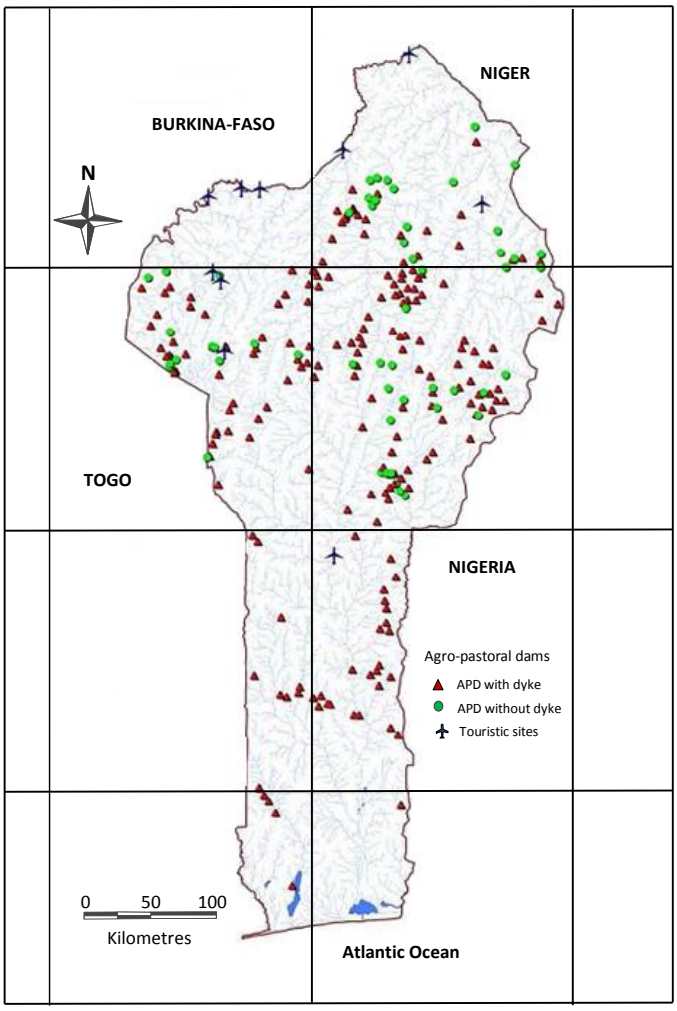

Figure 1.1 Distribution of agro-pastoral dams in Benin (Source: Adapted from Azonsi et al., 2008)

To address food security, the Benin government prioritizes the intensification of agricultural production, with produce such as maize, rice, vegetables, milk (from dairy production), and fish (MAEP, 2007). To reach this goal, the government of Benin initiated several development programmes such as the National Programme for Food Security (PNSA: *Programme National de Sécurité Alimentaire*), the Food Security through Agricultural Intensification Programme (PSAIA: *Programme de Sécurité Alimentaire par l'Intensification Agricole*), the Strategic Plan for the Revival of the Agricultural Sector (PSRSA: *Plan Stratégique pour la Relance du Secteur Agricole*), and the Emergency Support Programme for Food Security (PUASA: *Programme d'Urgence d'Appui à la Sécurité Alimentaire*). All these programmes pointed to APDs as having the potential to boost the agricultural sector through livestock production, fish production, and vegetable production; thus contributing to food security in Benin (MAEP, 2007; Gadelle, 2010). However, people who depend on the APDs have been facing problems such as infrastructural deterioration, degradation of watersheds and river banks, poor organization of involved stakeholders, underutilization of the agricultural potential of the dams, invasion of dams by crocodiles, conflicts between stakeholders, and so on (Capo-Chichi et al., 2009; Kpéra, 2009). Therefore, there is an urgent need to understand how and why APDs are used as they are used and to create conditions to optimize their use and management.

This thesis sheds light on the multi-purpose and multi-stakeholder use/management of APD ecosystem services in Benin with the aim of determining the optimal use and management of APD ecosystem services for the benefit of all the stakeholders involved. Comparative case studies of the use and management of three APDs in northern Benin are explored from an interdisciplinary perspective.

1.3 Problem statement and research objectives

Since 1970, Benin, like the sub-Saharan region in general, has been experiencing strong spatial and temporal rainfall variability due to inherent drought and climate change, with huge impacts on land and water resources (Fink et al., 2010; Bryan et al., 2013). APDs constructed in northern Benin to face these challenges have been used as multi-purpose facilities such as drinking water supply for humans, livestock watering place, fish farming, vegetable production, food cropping, cotton farming, cleaning, washing, swimming, domestic purposes, small business water use, brick making, and house and road construction (see Figures 1.2 and

1.3) (Kpéra et al., 2012). As APDs are open for public use, they are considered a common good (Hardin, 1968; Vollan and Ostrom, 2010). Because they involve many users with different backgrounds, knowledge, interests, views, assumptions, and practices, their management has become a complex issue (Mason, 2009), resulting in different kinds of conflicts.

Figure 1.2 Cattle watering in Fombawi APD, April 2011 (Source: Kpéra, G.N., April 2011)

Figure 1.3 Fishermen setting nets for fishing in Nikki APD, March 2010 (Source: Kpéra, G.N., March 2010)

A scoping study conducted in northern Benin in 2009 identified a number of issues hindering the use and management of the dams, such as:

1) Technical issues (decrease in vegetable yield, lack of mineral fertilizers, lack of materials and seeds, destruction of fences by cattle, dyke damage by crocodiles, and so forth);
2) Institutional issues (access to credit, vegetable producers' difficulties in accessing potential markets, non-respect of rules and regulations, and so forth);
3) Ecological issues (silting of the APDs, increasing drought, water pollution, depletion of fish production, predation of crocodiles on fish species, deforestation, and so forth) (Kpéra, 2009).

These issues appear to be at the root of all kinds of problems relating to multi-user water management in this region. Water management responsibilities were found to be fragmented, with little regard for either the conflicts or the complementarities among the stakeholders' diverse social, cultural, economic, ecological, and environmental backgrounds and interests.

In addition, the presence of fish species like *Oreochromis niloticus*, *Tilapia mariae*, *Clarias gariepinus*, and *Clarias anguillaris*, as well the permanence of water, have attracted crocodiles to the APDs. Local people frame the crocodile as lying at "*the heart*" of the APDs

because they maintain the water in the dams by digging holes so that the groundwater can be reached (Kpéra, 2009). In addition to this positive frame, crocodiles have a negative reputation as they may be aggressive and prey on fish species. Thus, people living around the dams have problems with the presence of crocodiles.

As APDs are public goods (Ostrom, 2009), each stakeholder tends to maximize the use of the dams, resulting in recurrent conflicts between herders and farmers, and between humans and crocodiles (Kpéra, 2009), and in the destruction of the ecosystem on which they depend for their livelihood.

Several studies have pointed out problems and opportunities relating to the multi-use and management of dams in West Africa (Roncoli et al., 2009; Sally et al., 2011; Venot and Krishnan, 2011; Venot and Clement, 2013; Venot and Hirvonen, 2013; de Fraiture et al., 2014). There is still, however, a lack of knowledge about the way stakeholders involved in dams could mitigate the constraints that they face and seize opportunities to improve their livelihoods. The aspiration in this thesis is to provide an in-depth understanding of the use and management of dams with the aim of developing innovative ways to improve APD use, taking into account ecological, socio-cultural, and institutional aspects of natural resources management.

The purpose of this research is to shed light on how stakeholders use and manage the APDs, including their effects on the main local income-generating activities (vegetable and fishing) and on water quality. The relationships between humans and crocodiles are studied with the aim of finding ways for people and crocodiles to peacefully share the dams. Based on the insights from this study, recommendations are developed for optimizing the use and management of dams for all stakeholders involved, including crocodiles.

More specifically, this thesis intends to:

1) To identify physical, social, and institutional impediments and opportunities in relation to the use and management of agro-pastoral dams (Chapters 2, 3, 4, 5);
2) To sharpen our understanding of how local stakeholders frame the presence of crocodiles, and the formal and informal institutions that people use to cope with them (Chapter 3);
3) To examine the challenges for smallholder vegetable producers when they are using the agro-pastoral dams (Chapter 4);
4) To analyse the impact of sharing agro-pastoral dam ecosystem services on water quality, fish diversity, and fish biomass (Chapter 5).

1.4 Research setting

The research area covers three APDs and the local communities making use of these APDs (Nikki, Sakabansi, and Fombawi) in Nikki District, Borgou Department, north-eastern Benin (Figure 1.4).

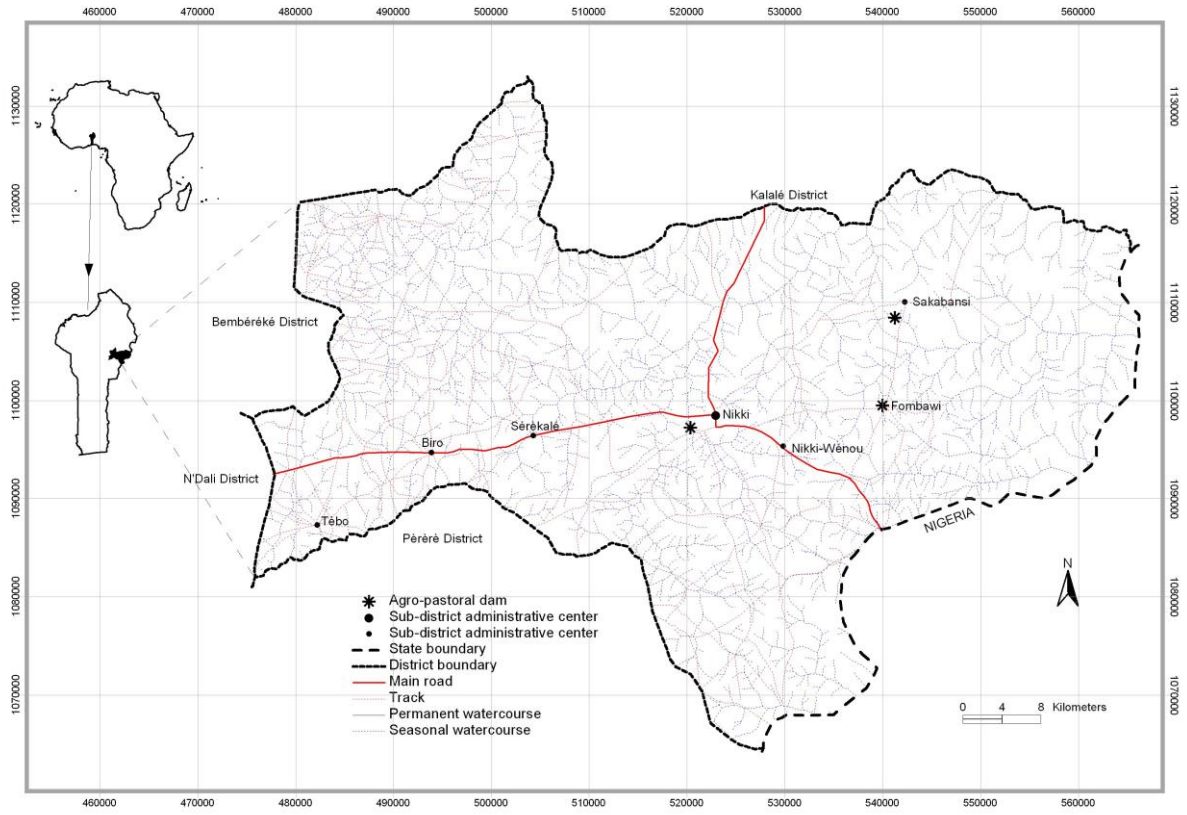

Figure 1.4 Location of Nikki, Sakabansi, and Fombawi agro-pastoral dams (Source: Kpéra, 2010)

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. These water infrastructures aim to enhance users' incomes by improving and supporting agricultural production (Capo-Chichi et al., 2009). Local communities engage mainly in farming, herding, and fishing, and receive a cash income from trading their products and from other activities.

1.5 Research approach and research questions

The research perspective is based on the integral ecology framework that helped to find relevant research questions and that provided an approach to methodological orientation and to interpreting empirical results. A case study approach was used as the overarching research design.

1.5.1 Integral ecology framework for finding relevant, mutually coherent questions

Given the major problems of our society today, it seems that the world is becoming more complex because of the involvement of different actors with diverse frames of reference, different prior knowledge at different levels (global/national/local), and different interests (Wilber, 1996; Leeuwis and Aarts, 2011). Wilber (1996) argues that solution building to deal with the complexity that we experience in our daily lives is compromised without a framework with a global vision that contains various perspectives in a way that links, leverages, correlates, and aligns these perspectives. Integral ecology (IE) provides a comprehensive framework for considering multiple approaches to ecological and environmental phenomena, including our embeddedness in these (Esbjörn-Hargens and Zimmerman, 2009). In order to arrive at the best possible solutions to environmental problems and conflicts, IE takes into account all pertinent perspectives (Esbjörn-Hargens, 2005; Zimmerman, 2005). According to integral ecology theory, four irreducible perspectives (objective, interobjective, subjective, and intersubjective) must be considered when one is attempting to understand and remedy environmental problems. These perspectives are represented by four quadrants: the interior and the exterior of individual and collective realities. These four quadrants represent the intentional ("I"), cultural ("we"), behavioural ("it"), and social ("its") aspects of ecological issues (see Figure 1.5).

The *upper left (UL) quadrant* (subjective, intentional) denotes the *terrain of experience*. IE recognizes that psychological capacities, states of consciousness, beliefs, and mental conditioning all shape people's individual attitudes about issues at stake. People's own experiences, as well as those of others, in relation to APDs play an important role in how stakeholders approach conflicts.

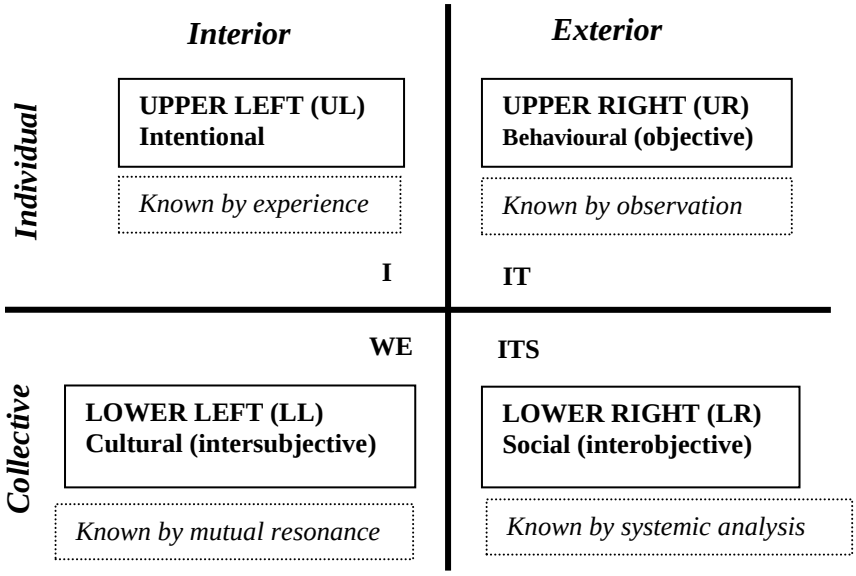

Figure 1.5 The four quadrants of integral ecology (Source: Esbjörn-Hargens and Zimmerman, 2009)

The *lower left (LL) quadrant* (intersubjective, cultural) represents the *terrain of culture*. It refers to the humanities, which examine and critically evaluate the intersubjective experiences, ideologies, belief systems, and norms and values of cultures. This quadrant invites the study of the specific cultural beliefs relating to the presence of crocodiles in the APDs, including how these beliefs are constructed and applied in interaction.

The *upper right (UR) quadrant* (objective, behavioural) symbolizes the *terrain of behaviour*. It includes most of the natural sciences, which focus on analysing and developing predictive capability. Here, it is a matter of observing, measuring, and describing what is going on in and around APDs.

Finally, the *lower right (LR) quadrant* (interobjective, social) indicates the *terrain of systems*. It embraces the social sciences and the systemic natural sciences, such as ecosystem biology. The focus is on the systemic structures and behaviour of collectives, ranging from socio-economic systems (including formal organizations, rules, and authorities) to ecosystems relating to the APDs.

To deal with complexity and to organize a peaceful coexistence between stakeholders, an innovation process should be designed to realize a breakthrough that changes both the perceptions and the practices of all stakeholders. Such an innovation process starts from the design and implementation of a coherent research programme for which this thesis delivers

important building blocks. In order to structure relevant research questions, the integral ecology model as explained by Esbjörn-Hargens and Zimmerman (2009) is used, resulting in various perspectives from which the use and management of APDs is considered. Applying the IE model helps to finding appropriate, mutually coherent research questions and research methods (Figure 1.6).

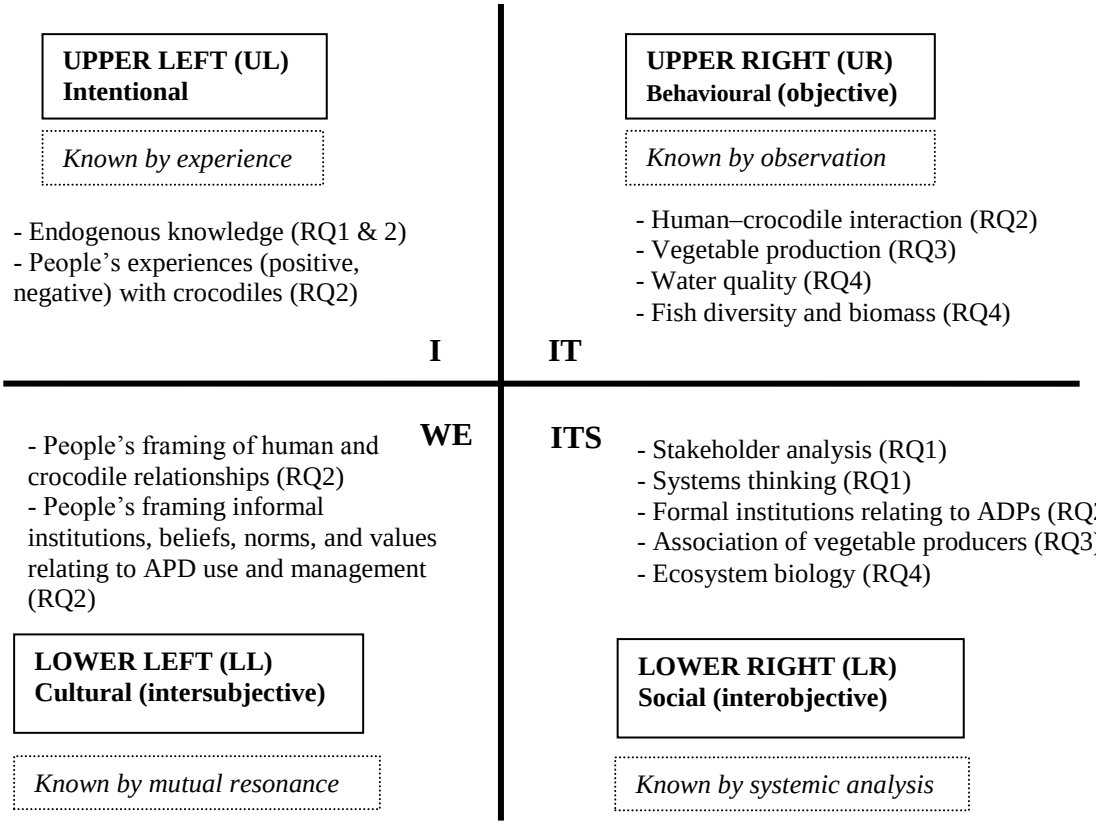

Figure 1.6 The four quadrants of integral ecology applied to APDs in relation to relevant research questions (Source: Adapted from Esbjörn-Hargens and Zimmerman, 2009) *(RQ = Research question)*

The terrain of experience (UL)

The different stakeholders involved in the use and management of APDs have experiences and expectations that contribute to their problem perceptions and their appreciation of specific solutions. These include endogenous knowledge (RQ1 and RQ2) and people's experiences (positive and negative) in addressing conflicts relating to the sharing of APD ecosystem services and to the presence of crocodiles. The relevant data are gathered by means of interviews (RQ2).

The terrain of culture (LL)

People's views and related socially constructed and shared institutions are addressed. We put emphasis on informal institutions (beliefs, norms, values, traditions, narratives, and discourses, an so forth) that collectively make sense and shape stakeholders' behaviours. In this research, such institutions are related to the rules that guide stakeholders in the use and management of APDs (RQ1) and in their interaction with crocodiles (RQ2). In relation to the subjective and the intersubjective perspective, the concept of framing (see 1.5.2) becomes relevant. Interviews, informal talk, focus group discussions, and participatory observation are used for data collection.

The terrain of behaviour (UR)

From this terrain, we focus on tangible, empirically observable features, for instance the visible behaviours and practices relating to the use and/or management of the APDs. The interactions between people and crocodiles in different contexts are included (RQ2). This terrain also points to important measurable features relating to water quality (RQ4), the APD ecosystem biology, fish biodiversity and biomass (RQ4), and vegetable production (RQ3). In other words, it is important to understand how users' behaviours during their daily activities around the dams contribute to environmental problems or affect APD ecosystem services and functions.

The terrain of systems (LR)

From this terrain, the formal association of stakeholders (who is involved, how do people relate to one another?) is studied, as also the formal institutions that guide practices (RQ2), including professional stakeholders involved, more specifically the association of vegetable producers (RQ3) and the ecosystem biology, i.e. the relations between water quality, fish diversity and biomass, crocodiles, humans, and livestock (RQ4).

On the basis of these four integral ecology quadrants, the following research questions are formulated:

*1- What are the technical and institutional impediments and opportunities in relation to APD management**?***

1.1. Who are the stakeholders involved in agro-pastoral dam use and management?

1.2. What are the important institutional and technical impediments and opportunities in relation to the use and management of the dams as perceived by the stakeholders?

2- How do stakeholders cope with the presence of crocodiles, and what are the main consequences?

2.1. How do stakeholders involved in APDs frame the presence of crocodiles in terms of problems and solutions?

2.2. Which formal and informal institutions do stakeholders use to deal with crocodiles, with what effect?

3- How does dry season vegetable production benefit from agro-pastoral dam ecosystem services and influence the dam ecosystem?

3.1. What are the characteristics of vegetable producers around the APDs?

3.2. What cropping systems do the vegetable producers use?

3.3. What constraints hinder vegetable production?

3.4. How are vegetable producers around APDs organized?

4- What is the impact of sharing the agro-pastoral dam on ecosystem services?

4.1. What is the physical, chemical, and microbiological quality of the agro-pastoral dam water?

4.2. What fish diversity and biomass are to be found in the agro-pastoral dam?

1.5.2 Methodological orientation of the study: the construction of reality in interaction, frames, and framing

We start this research from the idea that realities are constructed through communication among people (Ford, 1999; Gray, 2003; Aarts and van Woerkum, 2006; Dewulf et al., 2009; Shmueli et al., 2006; Idrissou et al., 2011a; Idrissou et al., 2011b). The reality that we know is interpreted, constructed, enacted, and maintained through discourse (Berger and Luckmann, 1966; Weick, 1975). From this point of view, problems, causes, and solutions are not given, but created in interaction among people in different settings. We thus live in a world that is variously understood (Yanow, 2000), and this requires an interpretive research approach.

At the most basic level, conversations are "what is said and listened to" between people (Ford, 1999). Analysing conversations in the APD context gives insight into the way people experience the involvement of several stakeholders in the use of APDs and the

presence of crocodiles, as well as into the context insofar as people find this important and thus take it into account. The concept of framing is used to understand the rules that govern our appreciation of our world and enables us to differentiate between different sorts of reality (Goffman, 1974). Framing starts from the idea that people in interaction co-construct stories about the world around them that help them to deal with problems and uncertainties and to accomplish goals. If interacting people frame an event or a phenomenon, they emphasize certain aspects, and other aspects are automatically pushed into the background (Entman, 1993; Aarts and van Woerkum, 2006; Dewulf et al., 2009). Framing has to do with making sense, interpreting, and giving meaning to what is happening in the ongoing world. People make sense of situations for themselves and for others by means of certain perspectives or frames that they deploy in interaction (Dewulf et al., 2009). In conversations with others, realities are constructed by means of framing, including formal and informal rules that govern our daily practices. As Aarts and van Woerkum (2006) argue, frames determine the interaction and are formed in the interaction by the experiences, expectancies, and goals that are being considered by the people at that very instant.

Since constructed realities provide the context in which people act and interact (Ford, 1999), change depends on the ongoing background conversations that are happening and that create the context for both the change initiative and the responses to it (Ford et al., 2002; Ford and Ford, 1995). Insights into such processes of frame construction are used in this thesis as building blocks for developing the innovation process needed to change the current dam use and management. The framing concept provides a relevant perspective for systematically analysing interviews, focus group discussions, informal talk, and participatory observations.

1.5.3 Case study design

A comparative case study approach is used as the overarching research design. The case study method is suitable for this research as we are trying to illuminate a phenomenon in its natural setting using multiple data collection methods to gather information from one or a few entities (people, groups, organizations) (Eisendhardt, 1989). Case studies enable the development of richly textured information that can be used to explain complex patterns, correlations, and causal links in real-life situations, and to describe the real-life context in which interventions take place (Yin, 2002; Thatcher, 2006).

1.5.4 The selection of cases

The study was carried out in the Nikki, Sakabansi, and Fombawi APDs. The local communities living around the APDs depend for their livelihood on food crops and cotton production, livestock farming, fishing, and trading agricultural products. Potential markets for food crops and cotton, fish, vegetables, and livestock exist in Nikki District, in its neighbouring districts, and in Nigeria (22 km from Nikki town) (Houngnihin, 2006). Agro-pastoral dams in these three villages were selected because they differ in terms of size, river source, number of users, diversity of stakeholders involved, frequency of fishing, number of crocodiles living in the dams, and local traditions and beliefs of people living in the different villages. At the same time, the villages are comparable in terms of location (Nikki District), types of livelihood supports, and the diversity of stakeholders involved. The features of each dam (Kpéra et al., 2012) are presented in Table 1.1.

Table 1.1 Main features of Nikki, Sakabansi and Fombawi agro-pastoral dams

	Nikki	Sakabansi	Fombawi
Inhabitants	31,661	2,072	1,490
Year of dam construction	1972 renovated in 1996	1985	1989
River	Sora	Samana	Kuena
Capacity (m^3)	257,000	200,000	170,000
Catchment basin (km^2)	120	20	2.4
Distance of the dam from the town/village (km)	2	3	0.3
Fishing frequency	Once or twice a day	Yearly	Yearly
Number of crocodiles	< 20	> 100	> 300
Human–crocodile relationships	In between	Conflict	Collaboration

1.5.5 Research and data collection processes

This thesis was undertaken within the framework of the Convergence of Sciences-Strengthening Innovation Systems (CoS-SIS) Research Programme (www.cos-sis.org). CoS-SIS was designed to focus on the interfaces between (1) the opportunities and constraints of smallholders and (2) the enabling/disabling institutional conditions at levels higher than the local level (Hounkonnou et al., 2012; Röling et al., 2012; Struik et al., 2014). This thesis focuses on local practices in APDs and on the constraints and opportunities experienced at

that level. It analyses the institutional and technical contexts relating to those constraints and opportunities that local people address for APD use and management. The scoping study (Kpéra, 2009) from which the main research objective was derived, and the diagnostic study that identified the interactively designed studies, serve as core components of the research process (Figure 1.7).

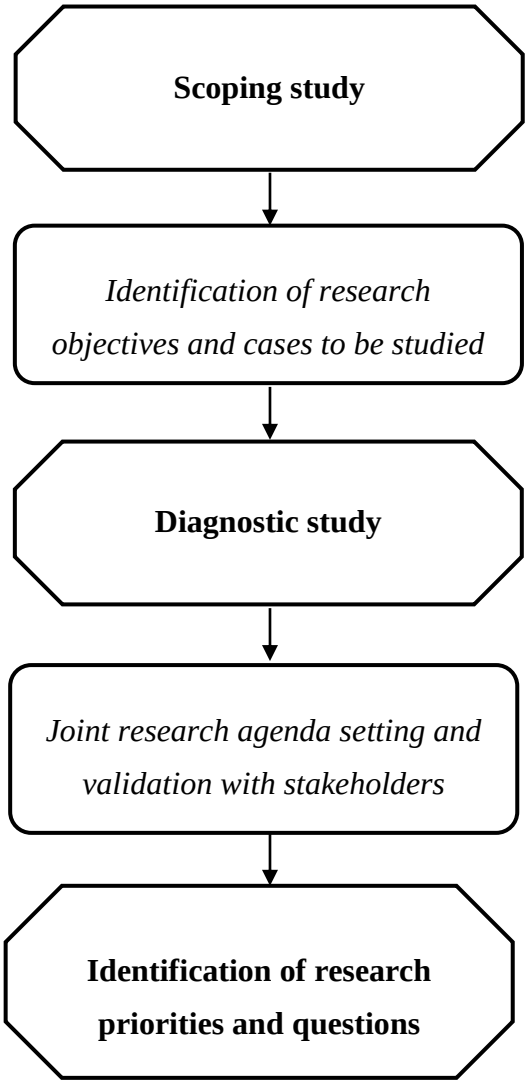

Figure 1.7 Overall research process

1.6 Thesis outline

This thesis investigates the multi-purpose and multi-stakeholder use and management of APD ecosystem services in Benin from different perspectives. It consists of six chapters, including an introduction, four empirical chapters, and a discussion and conclusions chapter, as visualized in Figure 1.8.

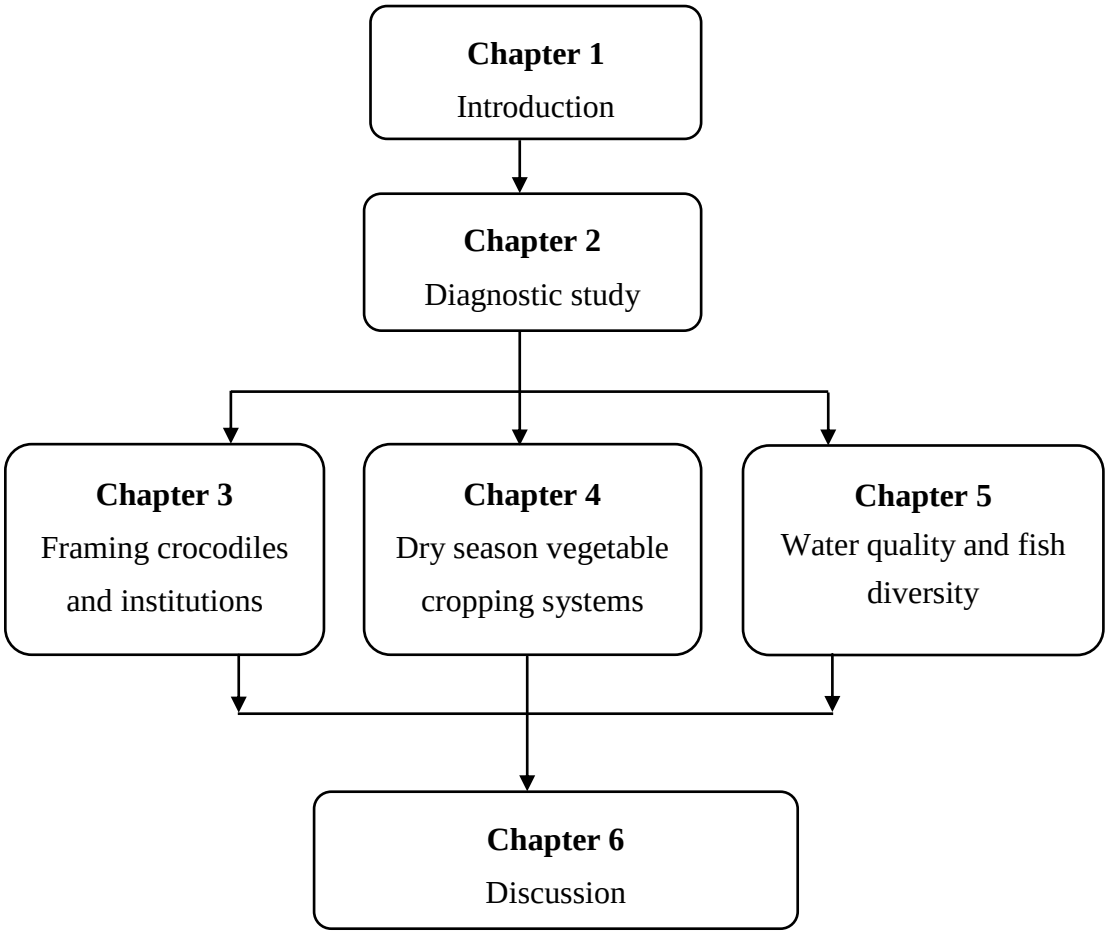

Figure 1.8 Overview of the thesis structure

The general introduction (**Chapter 1**) briefly describes the challenges relating to the use and management of APDs and identifies the knowledge gap that we address in this study. It also presents the overall research approach.

We start with a diagnostic study in **Chapter 2** from which the other studies are derived (Chapters 3, 4, and 5). The stakeholders involved in APD use and management are introduced. Important institutional and technical impediments and opportunities relating to dam use and management are identified, as perceived by the stakeholders. Furthermore, light is shed on a coherent set of domains for research.

In **Chapter 3**, we sharpen our understanding of the way stakeholders frame the presence of crocodiles and the institutions (formal and informal) that people use to cope with crocodiles. This chapter elucidates stakeholders' different experiences with crocodile damage in terms of the number of crocodiles and the nature of human behaviour.

Chapter 4 looks at the dry season vegetable production systems around APDs. We identify constraints that hinder this activity and shed light on how vegetable producers could benefit from the multiple opportunities that exist. Potential effects on the APD ecosystem are discussed.

In **Chapter 5**, we assess the health status of the agro-pastoral dam ecosystem, choosing water quality (the physical, chemical, and microbiological compositions) and fish diversity and biomass as indicators.

The thesis concludes with a discussion (**Chapter 6**) that binds together the findings of the implemented research approach, analyses the strengths and the limitations of the findings presented in earlier chapters, and provides suggestions that may contribute to crocodiles and other involved stakeholders peacefully and sustainably sharing the APD ecosystem services and improving APD users' livelihoods. Finally, suggestions are made about avenues for future research.

CHAPTER 2

Management of agro-pastoral dams in Benin: stakeholders, institutions and rehabilitation research

G.N. Kpéra[a], N. Aarts[b], A. Saïdou[c], R.C. Tossou[d], C.H.A.M. Eilers[e], G.A. Mensah[f], B.A. Sinsin[g], D.K. Kossou[c], A.J. van der Zijpp[e]

[a] Institut National des Recherches Agricoles du Bénin & Laboratoire d'Ecologie Appliquée, Faculté des Sciences Agronomiques, Université d'Abomey Calavi, Cotonou, Bénin

[b] Communication Strategies Group, Wageningen University, Wageningen, The Netherlands

[c] Département de Production Végétale, Faculté des Sciences Agronomiques, Université d'Abomey Calavi, Bénin

[d] Département d'Economie, de Sociologie Anthropologique et de Communication, Faculté des Sciences Agronomiques, Université d'Abomey Calavi, Bénin

[e] Animal Production Systems Group, Wageningen University, Wageningen, The Netherlands

[f] Institut National des Recherches Agricoles du Bénin, Abomey Calavi, Bénin

[g] Laboratoire d'Ecologie Appliquée, Faculté des Sciences Agronomiques, Université d'Abomey Calavi, Bénin

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Abstract

Agro-pastoral dams are waterholes constructed to provide water for livestock and for agricultural development. In Benin, agro-pastoral dams are managed by dam management committees. This study seeks to (1) characterize the stakeholders involved in agro-pastoral dam use and management, (2) identify important institutional and technical impediments and opportunities related to dams as perceived by the stakeholders, and (3) identify a coherent set of domains for research in support of improved dam management and ecosystem rehabilitation. The study was carried out in the Nikki District in northern Benin. The data were collected through focus group discussions, semi-structured interviews, participant observations and participatory exercises with diverse stakeholders. The results show that the dams are used for multiple purposes such as providing drinking water for livestock and people, fish production, vegetable production, swimming, bathing, washing, house construction, food crop production and cotton farming. All these practices involve diverse stakeholders with different interests, backgrounds, knowledge, and assumptions. In addition, the dams are the main habitat for crocodiles, which thus can also be seen as key stakeholders. The use and management of the dams create conflicts among the stakeholders who all tend to reproduce their own 'truth' and to shift the responsibility for solving conflicts to others. Moreover, the water is becoming seriously polluted, which impinges on every stakeholder's interests. The analysis indicates five domains for further research: (1) the way agro-pastoral dam water quality can be improved, (2) the mechanism through which to improve agro-pastoral dam fish production, (3) the way stakeholders in different contexts do frame crocodile behaviour and habitat use, (4) the characterization of crocodile behaviour and habitat use in agro-pastoral dams, and (5) the way to promote an inclusive agro-pastoral dam management.

Key words: multiple resource use, water pollution, complex conflict, crocodiles.

2.1 Introduction

Water access and availability are emerging as critical challenges to sustainable development in the 21st century (Barlow et al., 2004; Conca, 2008). Water plays a key role in society in terms of food, energy, and industrial activities. It also plays a critical role in physical and

biological processes, through runoff, groundwater flows, soil moisture replenishment and other ecosystem functions (Power, 2010). Pressure on water resources and ecosystems, resulting from urbanization, population growth, land use change, increased irrigation, construction of dams, pollution, climate change and other impacts related to human activities and economic growth need to be addressed urgently at both local and global level (WWD, 2009; Birol et al., 2010; Zander et al., 2010).

In Benin, the water and grazing requirements for livestock (Djenontin et al., 2003) are the major impediments for the development of livestock production. The severe drought of 1970, which caused high ruminant (cattle, sheep and goats) mortality compelled the government to promote agro-pastoral dams (APDs), managed by dam management committees (CoGes) in order to provide additional drinking water for livestock and agricultural development (Capo-Chichi et al., 2009). The promotion of waterholes is one of the priorities identified by the Benin government for improving production systems (Capo-Chichi et al., 2009). The waterholes are open for public use and thus are considered a common good (Hardin, 1968; Vollan and Ostrom, 2010; Pires and Moreto, 2011) by a multiplicity of actors. APD management thus has become a complex issue (Mason, 2009; Pahl-Wostl, 2007; Wallis and Ison, 2011). The present situation could be characterized as exemplifying the tragedy of the commons (Hardin, 1968). Trying to achieve a solution by means of centrally imposed taxes or quotas may fail in part because central authorities misunderstand the local situation.

In recent efforts to optimize the management of the APDs in northern Benin, the invasion of the dams by crocodiles, which are considered by some stakeholders to be one of the main hindrances to fish production and to the sustainable use of the dams, has been pinpointed as a major constraint (Capo-Chichi et al., 2009; Kpéra, 2009; Kpéra et al., 2011). At the same time, the northern Benin crocodile species are considered by national and international experts to be in danger of extinction (IUCN, 2010; Kpéra et al., 2011), leading to demands for their protection (IUCN, 2010). So the challenge is to find innovative ways to optimize dam use and management from the perspective of integrated water resources management, taking into account social, environmental, technical and institutional aspects and the interests and practices of all actors involved, including the crocodiles. This seems likely to require forms of water management decision-making that are flexible, holistic, and environmentally sound (Pahl-Wostl, 2007).

An exploratory study conducted in northern Benin in 2009 confirmed that the dams have multifunctional uses and identified a number of technical, institutional and ecological

issues (Wallis and Ison, 2011) that appear to be at the root of the problems relating to multi-user water management in this region. Water management responsibilities were found to be fragmented, with little regard for either the conflicts or complementarities among the stakeholders' diverse, social, cultural, economic, ecological and environmental objectives. On the basis of that study, the justifications for an in-depth diagnostic study were identified.

The aim of this diagnostic study is to provide the first description of the so far unexplored situation and develop research priorities that aim to contribute to the design of an innovation process for improving the situation at grass roots level. The focus is on managers' and users' practices and perceptions, taking into account both formal and informal institutions that might enable or hinder innovation. The specific purposes of this study are (1) to characterize the stakeholders involved in agro-pastoral dam management, (2) to identify their practices and perceptions in relation to dam use and management, (3) to identify important institutional and technical impediments and opportunities, and (4) to identify a set of researchable domains to support effective and sustainable dam use and management.

2.2 Methodology

2.2.1 Framing change and innovation

The methodology of our study is framed by the idea that innovation is a collective process that involves the contextual re-ordering of relations in multiple social networks (Leeuwis and Aarts, 2011). Such a re-ordering cannot be usefully understood in terms of 'diffusing' ready-made solutions. In the development and design of innovation, everyday communicative exchanges and self-organization amongst actors are likely to be of critical significance in connection with the reordering.

Innovation studies suggest that complex interdependencies and regularized interaction (including communication) patterns tend to constrain the space for meaningful innovation, not in the least since a number of the actors in a network are likely to have a vested interest in maintaining the existing situation. Such vested interests are expressed in the prevailing formal and informal societal rules and arrangements that actors draw upon and reproduce in their interaction (Giddens, 1984; Loorbach, 2007). Despite such constraints, and despite the experience that deliberately designed change is not easily achieved, we see that societal relations change continuously – and quite radically at times. Self-organization i.e., the

emergence of order without external control (Nicolis, 1989), plays an important role in bringing about patterns of change. The term self-organization does not mean that change happens automatically and without human intentionality; change emerges as the unintended outcome of numerous intentional actions that interact and interfere with each other in complex ways (Scharpf, 1978; Aarts and van Woerkum, 2002; Castells, 2004; Aarts et al., 2007). This perspective suggests that latent opportunities for change always exist (even if unacknowledged) and that societal contexts and structural conditions are not only constraining but also enabling (Giddens, 1984). In this framing, it is relevant to think about the space for innovation (Cornwall, 2004); in a general sense, this might be thought of as the room for manoeuvre that exists or emerges in a network of interactions occurring at multiple social interfaces.

This approach to change and innovation is connected to theories of complexity (Prigogine and Stengers, 1984). The behaviours of people are positioned as conditioned by numerous variables and we cannot count on linear serials of causes and consequences to explain the change dynamic. We assume in this paper that each activity associated with the dams involves numerous stakeholders interacting with each other in diverse ways leading to either co-operation or conflict among them and that improved dam management can be found only if the actors take into account the system of interactions as a whole (Burnes, 2005; Leeuwis and Aarts, 2011).

2.2.2 Research setting

The study was carried out in three villages (Nikki, Sakabansi and Fombawi) in Nikki District, which lies in the Borgou Department in north-eastern Benin (Figure 2.1).

Nikki District covers an area of 3171 km^2 and houses 20 agro-pastoral dams (Capo-Chichi et al., 2009). The main sources of livelihood of the local communities are crop production, livestock farming, fishing and trade of agricultural products (Capo-Chichi et al., 2009). The three main dams are:

1) The Nikki agro-pastoral dam, constructed in 1972 and renovated in 1996 by the United Nations Capital Development Fund (UNCDF). It has a capacity of 257,000 m^3; the surrounding watershed is 120 km^2 (Capo-Chichi et al., 2009). It is located within the boundaries of Nikki town. The annual influx of livestock gives rise to conflicts between herders and farmers. Fishing is carried out at least two times a day. Crocodiles live in the dam and are regarded as an impediment to fish farming.

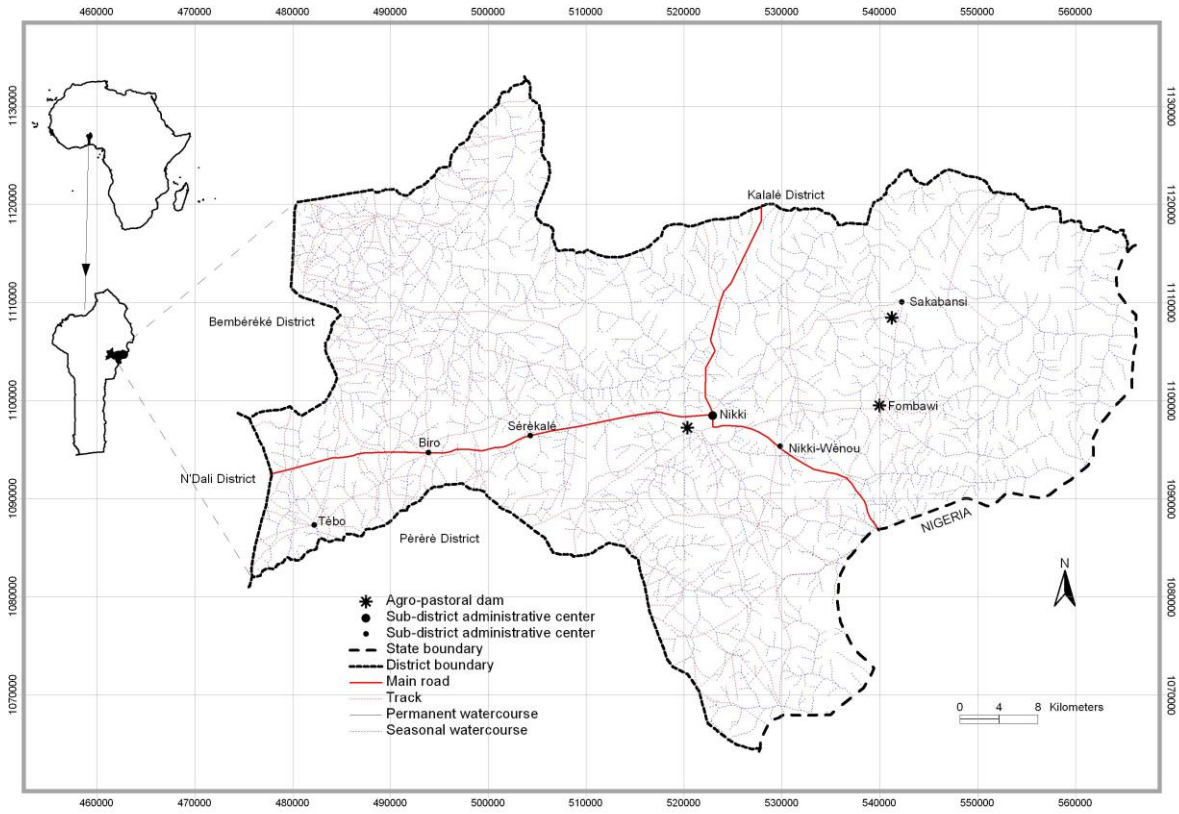

Figure 1.4 Location of Nikki, Sakabansi and Fombawi agro-pastoral dams (Source: Kpéra G.N., 2010)

2) The Sakabansi agro-pastoral dam. The dam has a surface area of 1 ha, has a capacity of 200,000 m^3 and is surrounded by a watershed of 20 km^2. It was constructed in 1985 by the Development Project of Livestock East-Borgou (PESB) with the financial support of the Development Aid Funds (FAD) (Capo-Chichi et al., 2009). Because of its geographical position the dam is mainly used to provide additional drinking water for livestock. It lies at crossroads for transhumant herders from the bordering districts and countries, and conflicts between herders and farmers are common. Fish production is a secondary activity that also is hindered by the presence of crocodiles.
3) The Fombawi agro-pastoral dam, constructed in 1989 under the financial support of the United Nations Development Programme (UNDP) and under the East-Borgou Development Project of Livestock (PDEBE) in Benin. The dam has a capacity of 17,000 m^3 and is surrounded by a watershed of 2.4 km^2 (Capo-Chichi et al., 2009). Its geographical position means that it is used by national and international transhumant livestock and this periodically intensifies farmer–herder conflicts. Fishing takes place only once a year because of the high number of crocodiles that hinders this activity. Unlike the Nikki and Sakabansi dams, here the crocodiles are honoured because they represent the

cultural identity of the local people, who protect them by means of traditional institutions and have developed considerable knowledge related to the ecology, behaviour and endogenous conservation of crocodiles.

2.2.3 Research methodology

The study seeks to provide an in-depth understanding of the on-going dynamics in stakeholders' relationships at the interface between the formal arrangements and self-organized initiatives governing their interaction. Because case studies enable the development of richly textured information they may be used to explain complex causal links in real-life situations and to describe the real-life context in which interventions take place (Yin, 1984; 1994). A comparative case-study approach has been chosen as the overarching research design.

Case study methods involve an in-depth, longitudinal examination of a single instance or event: a case. A case study provides a systematic way of looking at events, collecting data, analysing information, and reporting the results. The researcher may gain a sharpened understanding of why the instance happened as it did, and of what is important to look at more extensively in future research. Case study research also has limitations: generalizations cannot be made and the results are not widely applicable. However, case study research may allow analytical generalization.

Because of the diagnostic nature of our study largely qualitative methods were used. We started with a desk study leading to archival data collection from various departments with responsibilities for water and livestock management at the Ministry of Agriculture, Livestock Farming and Fishery (MAEP: *Ministère de l'Agriculture de l'Elevage et de la Pêche*), the Department of Forest and Natural Resources Management (DGFRN: *Direction Générale des Forêts et des Ressources Naturelles*), the Agricultural Engineering Service (DGR: *Direction du Génie Rural*) and the Hydraulic Service. Data on stakeholders' perceptions of the management and use of the dams was obtained through 19 focus group discussions (FGD) (Wong, 2008) whose members were drawn from amongst each of the stakeholder categories identified in the three study villages (yielding 7 FGDs in Nikki, 7 in Sakabansi and 5 in Fombawi). A stakeholder analysis (Stanghellini, 2010) was carried out to identify the stakeholder categories. The analysis also allowed the researcher to develop a preliminary understanding of stakeholders' behaviour, intentions, and interests. The snowball technique was used to identify representatives of each stakeholder category and these were

invited to join the focus group discussions. The snowball technique yields a sample based on referrals made by people who share, or know others who present the characteristics that are of research interest (Biernacki and Waldford, 1981).

The resultant focus groups consisted of seven to nine men and women who were involved in one of the following specific focus activities: vegetable farming, herding, non-vegetable farming, fishing, and membership of a dam management committee. Members of the council, women washing kitchenware and clothes around dams, and children who swim in the dam were also included. The focus group method surfaces and explores meanings and rationalities with respect to water practices at the group level and in interaction between the researcher and the participants (Heggera et al., 2011).

The snowball technique was used also to identify male and female respondents in each stakeholder category, with whom twelve, eight and seven individual semi-structured interviews (SSIs) were held in respectively Nikki, Sakabansi and Fombawi, in order to obtain more detailed information on their experience of activities, impediments and opportunities.

The discussions in the focus groups and the individual interviews were tape-recorded and transcribed. In addition, participant observations and participatory exercises (brainstorming and problem analysis), as well as numerous natural interviews, were used to identify additional impediments and opportunities. Finally, two stakeholder meetings with representatives of each category of stakeholders from Nikki, Sakabansi and Fombawi were organized in Nikki. The first meeting was attended by 22 participants and the second by 28 participants, and included herders, vegetable farmers, food crops and cotton farmers, dam management committee members, members of the council, daily users of the APDs, fishermen, dam security guards, local officers of MAEP and of the local union of herders (UCOPER: *Union Communale des Producteurs et Eleveurs de Ruminants*). At each of the two meetings the researcher first presented the preliminary findings, which were then discussed. The participants also listed and prioritized further items for research and intervention.

The data and information were analysed manually by comparing and contrasting the stories of the stakeholders in order to find patterns, such as the interdependence amongst activities related to stakeholders' diverse interests and backgrounds, and explanations for the identified conflicts and problems.

Table 2.1 summarizes the methods, the target respondents and the number of respondents per village.

Table 2.1 Objectives and methodology for data collection and analysis in the Nikki, Sakabansi and Fombawi agro-pastoral dam areas

Objectives	Tools/methodology	Targeted respondents	Number of respondents		
			Nikki	Sakabansi	Fombawi
Characterization of stakeholders involved in the agro-pastoral dams management	Desk study: archival data collection Focus group discussion Stakeholder analysis Snowball technique Tape-recording of interviews and transcription	Non-vegetable farmers, herders, vegetable producers, fishermen, dam management committees, Council of Nikki, women who wash kitchenware and clothes around the dams and children who swim in the dam, Agricultural Engineering Service (DGR), local officers of the Ministry of Agriculture, Livestock and Fishery (CeCPA)	56	56	45
Identification of stakeholders' practices and perceptions related to dam use and management	Focus group discussions Individual semi-structured interviews Participant observation Participatory exercises (brainstorming and problem analysis) Tape-recording of interviews and transcription	Herders, vegetable producers, non-vegetable farmers, dam management committee members, town council, daily users of the dams, fishermen, dam safe guards, local officers of the Ministry of Agriculture, Livestock Farming and Fishery, UCOPER, SNV, PADPPA	56	56	45
Identification of important institutional and technical impediments and opportunities to dam use and management	Focus group discussions Individual semi-structured interviews Participant observation Natural interviews Tape-recording of interviews and transcription	Herders, vegetable producers, non-vegetable farmers, dam management committee members, town council, daily users of the APDs, fishermen, dam safe guards, CeCPA, UCOPER, SNV, PADPPA	68	64	52
Identification a set of researchable questions to support effective and sustainable dam use and management	Stakeholder meetings Tape-recording of interviews and transcription	Herders, vegetable producers, non-vegetable farmers, dam management committee members, Council of Nikki, daily users of the APDs, fishermen, dam safe guards, CeCPA and UCOPER		50	

2.3 Results

2.3.1 The stakeholders in agro-pastoral dam use

The stakeholders in dam use and management are diverse. Two main categories were identified: (1) the users of the dams' ecosystem services (herders, vegetable farmers, food crops and cotton farmers with a farm near the dams, daily users of the dams, fishermen and crocodiles), and (2) governmental officers at local and at national level. We first describe their perceptions and practices related to dam use and management, including the problems and impediments they experience.

- Users

Based on information from the focus groups and interviews, our study shows that the diverse stakeholders use the agro-pastoral dams (APDs) for different goals and purposes. These sometimes allow other uses and goals to be respected but often exclude them, leading to conflicts. The main stakeholder groups include herders, vegetable farmers, food crops and cotton farmers, daily users, fishermen, dam management committee members and crocodiles.

- Herders

In all the areas studied, both farmers and herders are involved in livestock farming. The herds typically are mixed, consisting of cattle, sheep and goats, and belong to four sub-categories of stakeholders: (1) local farmers, (2) local herders, (3) herders from districts bordering Nikki and Segbana, and (4) herders from countries bordering Benin (Nigeria, Niger and Burkina Faso). Typically, the farmers own 2–10 animals and local herders 50–500 animals, whereas herders from the bordering districts and countries own 500–1000, mostly cattle. In the latter case, shortages of water and grass, particularly during the dry season, recurrently force the herders to migrate with their livestock over long distances from Niger, Nigeria and Burkina Faso into Benin.

A participant of one FGD noted that the local herders have contributed to the construction of the APDs because the APDs were perceived to be very beneficial to them:

> *They could water their livestock year-round without walking long distances. If our dam disappears, humans and livestock will suffer a lot and our livelihood will be negatively affected* (FGD, August 2010).

From 2001 onward the local herders have been organized by UCOPER (Union Communale des Producteurs et Eleveurs de Ruminants), a union open to herders from the whole district. According to both herders and UCOPER managers, UCOPER's main interest is to manage the conflicts between farmers and all four of the herder sub-categories, defend herders' interests, improve water quality and become highly involved in APD management. UCOPER participates also in the setting of national and international transhumance corridors that all categories of herders must follow to access the waterholes and pastures. However, according to farmers and other stakeholders, herders do not make use of these corridors because they want to escape the grazing-tax collectors. In addition, both local and transhumant cattle (i.e., cattle from districts bordering Nikki and Segbana and from countries bordering Benin) are herded by children who let the animals access the dams from all sides. The animals drink for 20–40 min and then graze around the dams on farmers' land where fresh grass is available even during the dry season. In addition, herders find the corridors too long and therefore they prefer to shorten the journey by passing across farmers' land. According to the farmers, this results in cattle and other animals destroying the farmers' crops and eating their grass. The herders, in turn, blame those farmers who, in order to extend their land, deliberately decide to obstruct the livestock corridors. During the rainy season, the conflicts are less: few livestock visit the dams because water is available from small ponds and rivers around the villages.

All the herders we talked claimed that the main impediments to the use of the APDs are the recurrent conflict between farmers and herders, water pollution, and the silting up of the dams. They blame the farmers for impeding access to the dams as well as the council of Nikki for taking a position favourable to the farmers. According to them, both native and transhumant herders are considered as strangers whose interests do not necessarily have to be taken into account. Moreover, several herders (70%) shared the following view:

> *We herders do not like politics. As the council knows that it cannot count on our vote to win elections, we are usually marginalized in favour of the farmers during conflict resolution* (Herder, Sakabansi, October 2010).

As far as water pollution is concerned, the herders do not see themselves to be the agents of the poor water quality. They shift the responsibility by saying:

> *The daily users of the APDs pollute water by washing and swimming in the dams, by defecating and by leaving household waste at the water edge. Vegetable growers and farmers of food crops and cotton around the APDs also pollute the water by using inorganic fertilizers and pesticides* (Herder, Fombawi, October 2010).

- Vegetable producers

Vegetable producers are organized in associations of farmers who grow vegetables around the APDs in the villages. At Nikki, two vegetable producers associations exist: Ansouroukoua association, initiated in 1990 with 20 members and now consisting of 150 members (130 women and 20 men), and Donmarou association, created in 2007 and consisting of 50 members (10 men and 40 women). Vegetable production at Nikki is carried out mainly in the dry season. The cropping area is located about 800 m upstream from the dam i.e., they do not use directly the water from the dam but instead dig small wells of 2–3 m deep. A large variety of vegetables is grown, among which the most common are: red amaranth, sesame, okra, tossa jute, hot pepper, African eggplant, roselle, silver cock's comb, wild cabbage, lettuce, tomato, carrot and onion. Individual plot size varies from 200 m^2 to 800 m^2. To fertilize the soil animal manure is used by 61% of the respondents; 39% use inorganic fertilizers because these are considered to be more effective than animal manure. We noticed people also making use of a bio-pesticide made locally from neem seeds and leaves and that the highly toxic synthetic pesticides endosulfan and lambda cyhalothrin C-profenofos – which formerly were recommended for use on cotton and currently are forbidden in Benin – are being used on the sly by vegetable growers.

At Fombawi, 32 women have organized themselves into an association for vegetable production, called Angara debu. Their main crops are red amaranth, sesame, okra, tossa jute, hot pepper, roselle, melon, lettuce and tomato. The plots are located downstream of the dam and the women draw water manually from the dam by using bowls. Animal manure is used as fertilizer and – although the women complain about its ineffectiveness – also plant ash is applied as a bio-pesticide. Since 2009 the women have stopped producing vegetables in Fombawi, because, as they said, their garden fence and their produces were many times destroyed by cattle. In addition, their products were destroyed by bush fires lit by 'dishonest people seeking giant field mice', which are considered an important delicacy.

The vegetable producers association of Ankua mon at Sakabansi was created in 1998 and counts nowadays 30 members (29 women and one man). The association was restructured in 2004 on the initiative of a support of the Roots and Tubers Developing Project (*PDRT: Projet de Développement des Racines et Tubercules*), which helped the members to obtain seeds and trained them in cropping techniques. As at Nikki, the vegetable plots are located upstream. The producers cultivate the same vegetables as in Fombawi. Compared with Nikki and Fombawi, the producers' plots are very small. Instead of getting water directly from the dam they dig small wells near their plots. Animal manure is used as fertilizer and plant ash as

a bio-pesticide. Because they greatly appreciate vegetable production, they are motivated to remove the impediments to production in order to improve their income. The vegetable producers' main concern is to get water and materials for their activity.

During the FGDs with the vegetable producers, and at the two stakeholder meetings, a number of technical impediments were listed, such as the decrease in vegetable yield because of diseases and pests, the lack of inorganic fertilizers, the lack of materials and seeds and, at Fombawi, the destruction of fences by cattle. The harassment in accessing credit and the difficultly in accessing potential markets for their products were also mentioned. Because only registered associations have easy access to the micro-credit allocated by the government and by non-governmental organizations all vegetable farmers have become members of an association.

The main opportunity for vegetable producers is that they are close to Nigeria, which is a large centre of commercial food crop marketing, but currently only the Nikki farmers take advantage of this market. However, they do not look to the council in Nikki for support in opening up this market; rather, the council is seen by the vegetable farmers as a threat. According to the farmers themselves, the council has accused the farmers of contributing significantly to the silting problem and to water pollution through their activities.

Attempts made by the dam management committee and the council of Nikki to expel the vegetable producers from their upstream to new downstream sites have not been successful for the following reasons as expressed by the producers themselves:

> *There is no infrastructure downstream; the new place is stony and dry and water is not easily available. (Woman vegetable producers, Sakabansi, November 2010), and: we are not the ones polluting the dam and this place is for everybody. We have the right to use it like we want. Even if you come here with a crane; we are not going to move* (Woman vegetable producers, Sakabansi, November 2010).

Once more, it can be noticed that it is 'the other stakeholders' who are blamed for the pollution and other problems.

Figure 2.2 presents women vegetable producers' minimum and maximum incomes in Nikki, Fombawi and Sakabansi. The income is higher in Nikki where vegetable producers have access to local markets and to a market in Nigeria (Tchikanda).

Regarding the sustainability of the dams, vegetable producers are aware of the grounds for concern in all the three cases. However, they say that everybody is trying to use the dams' resources to the maximum because what is important for them is their day-to-day life.

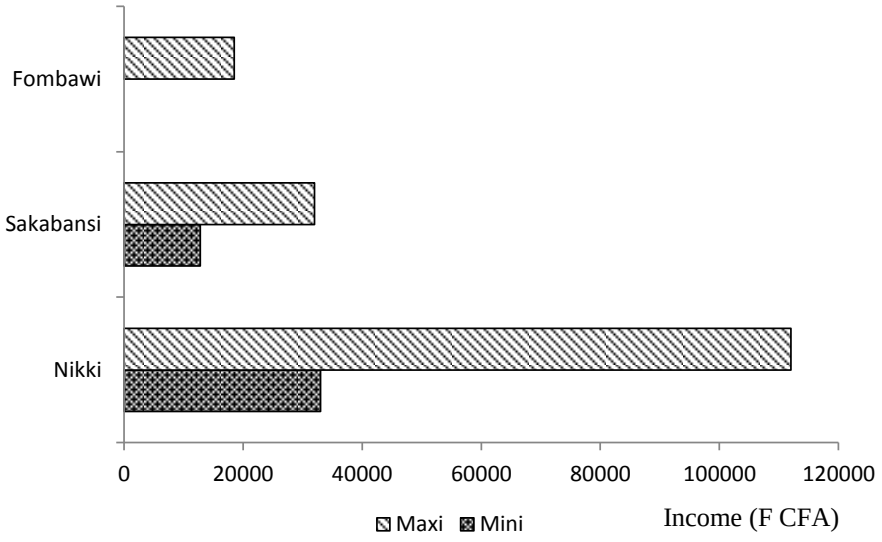

Figure 2.2 Women vegetable producers' minimum and maximum incomes in F CFA in Nikki, Sakabansi and Fombawi: average per season/woman (Source, interviews with vegetable producers, 2010)

- Food crops and cotton farmers

The food crops and cotton farmers who have a farm near the APDs are growing mainly maize, groundnut, soya bean, millet, sorghum, yam and cotton. It is common to see farms located at only 50 m from the edge of the water in the dams. The cropping system is characterized by the use of authorized inorganic fertilizers and pesticides. However, several farmers also use the prohibited organochlorine pesticides endosulfan (benzoepin), lindane (gamma-hexachlorocyclohexane), and DDT (dichlorodiphenyltrichloroethane). They indicated to us that they buy these chemicals from the Chikandou Market in Nigeria (located at 22 km from Nikki) because they are cheap.

Thirty-five percent of the farmers interviewed honestly recognized that they are contributing to the silting up of the dams and to water pollution. However, the majority (65%) of the respondents blame the herders, who allow livestock to urinate and defecate into the water. They also blame the daily users of the APDs for polluting the water by their activities: *Livestock urinate and defecate into the water, polluting the water. In addition, users wash and clean their things directly in the water* (Farmer, Fombawi, November 2010).

In all the three dam areas, the production of non-vegetables takes place in a radius of 1 km from the water's edge. A decision to displace these farms from this land has been taken by Nikki council. The farmers have been informed about this decision but it has not yet come into force. The farmers claim that land scarcity is the reason that they are cultivating this land

and why they do not want to leave. In addition, they refer to their grandfathers' land rights, which extended into the area now covered by the dam. According to the council, however, the area belonged in the past to certain families who voluntarily offered it to the village to accommodate the dams. The Council of Nikki recognizes that these donations unfortunately were made without a formal act supporting their land rights.

- Daily users

Every day, people visit the APDs for various purposes such as collecting water for drinking and domestic uses, washing (kitchenware, clothes, motorbikes and cars), swimming and bathing. As the APDs have no organized entrance or exit, access is free for everyone who wants to make use of the water.

During the dry season, finding water for domestic uses is an ordeal for many people. Most of the wells dry up and the only water available is drawn from ground wells by hydraulic pumps, which are costly to buy and operate; however, access to the APDs is free.
The women in Sakabansi and Fombawi use water from the dams for cooking, for other domestic uses and for drinking for two reasons as they say: (1) they are too poor to buy the clean water supplied by commercial water sellers; and (2) because everyone uses the water it would be fairer if everyone paid for using it. Others argue that they continue drinking the water of the dams simply because they have done so for many years without experiencing any problem. However, others seriously doubt the quality of the dams' water and see this practice as a health risk.

In addition, at Nikki the water is used in the construction of houses and roads and in Sakabansi and Fombawi in house construction. The Nikki council has decided that those who use the water for construction must pay 2000 FCFA (€ 3.05) per house under construction. The money is supposed to be collected by the treasurer of the dam management committee, who sends the amount collected to the Nikki council account. At Nikki, it is a guard who is responsible for collecting the payment as he is living near the dam. However, some people refuse to pay the money, arguing that the council is doing nothing to improve the quality or allocation of the dam water and as long as the dam water is treated as a common good they too have the right to use it freely.

The daily users' main interest is to continue to have free access to the dams. The presence of crocodiles is experienced as an impediment to access. In all the villages the silting up of the dams and the water quality are highlighted as additional problems in daily use.

- Fishermen

Fish farming is not open to everybody: the Council of Nikki employs registered fishermen who live in Nikki town or who come from Niger for temporary work. The fishermen receive 1/3 of their fish catch; 2/3 is in principle reserved for the council. The fishermen's main interest is to intensify fish production because their incomes depend on the fish yield. They also fish for themselves in the Niger River and the Ouémé River i.e., their livelihood does not completely depend on the APDs.

The fishermen claim that there has been a strong decrease in fish yield, caused principally by the silting up of the APDs, by longer drought periods, water pollution, and the lack of attention paid to these trends. Between 2006 and 2010, fish yield decreased in the whole district of Nikki, as illustrated by Figure 2.3. They also mentioned the invasion of the dams by aquatic plants and the lack of fishing equipment.

At all the three dam sites, crocodiles were identified both by fishermen and the dam users as one of the main hindrances to fish farming because of their high predation on three valuable fish species: the Nile tilapia (*Oreochromis niloticus*), the spotted tilapia (*Tilapia mariae*) and the African sharp tooth catfish (*Clarias gariepinus*). They claimed also that the crocodiles destroy fishing nets and the dam's infrastructure (by digging holes into the dyke). At Nikki and Sakabansi the crocodiles are hunted and killed and their meat, organs and skins sold. However, in Fombawi local people accept the presence of crocodiles and have created rules and behaviours that seem to allow them to live in peaceful co-habitation with the crocodiles.

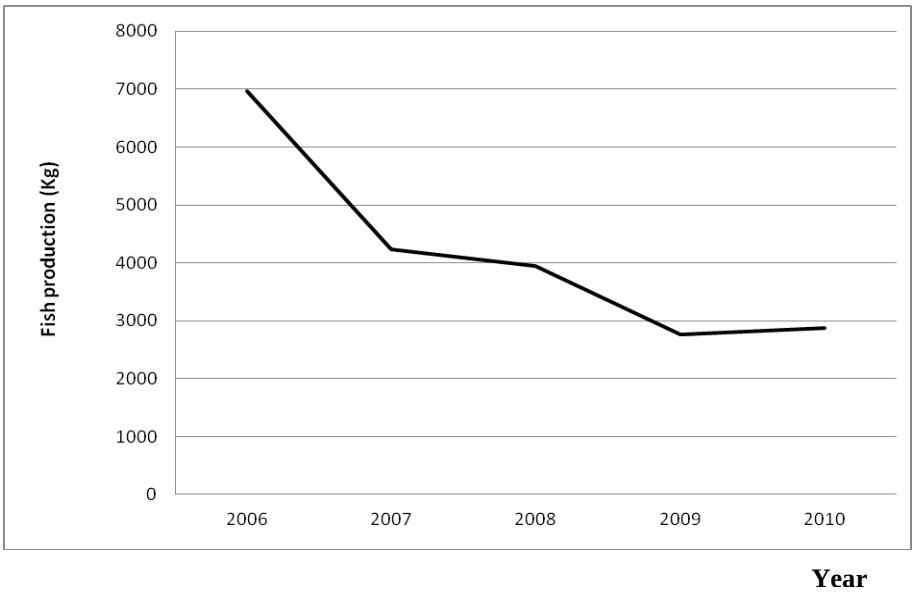

Figure 2.3 Fish production trend in kilogramme in Nikki District from 2006 to 2010

(Source, CeRPA Nikki, 2010)

- Dam management committee

Each dam is maintained by a dam management committee (CoGes: *Comité de Gestion du barrage*) consisting of seven to nine members, comprising farmers, herders and vegetable growers, who are considered the main dam ecosystem users. The main functions of the CoGes are to clean periodically the dams and the surrounding area, open transhumance corridors, prevent robbery of the fish, and control activities that contribute to the silting up of the dams and to water pollution. The CoGes members are selected by the Nikki council at a general assembly. The CoGes' powers are limited to the dam they are in charge of. The actual state of the APDs leads to serious doubts whether there is a sufficient performance of their functions. According to the members of the CoGes who were interviewed in this study, the informal deal is that the management committees take care of the dams and in compensation benefit from a kickback (amounting to 2/3 of the fish production per fishing session). The CoGes members confessed that they are not motivated to perform their official role because the informal deal is not respected.

- Crocodiles

Several species of wild animals occupy the dams, including snakes, monitor lizards, turtles and crocodiles. Crocodiles appear to be the most impressive of these animals both in number and in size, and people give them full attention. They occur in all the three dams but in different numbers. According to local people, crocodiles are rare in Nikki (less than 20), common in Sakabansi (20–100) and abundant in Fombawi (more than 200). Two crocodile species are said to occur in the dams: the West African crocodile (*Crocodylus suchus*) and the Dwarf crocodile (*Osteolaemus tetraspis*). However, only the first species was observed during this study. Most of the interviewed dam users stated that the invasion of crocodiles took place after the construction of the dams. In earlier times, old people testified, there were large numbers of crocodiles in the rivers and ponds and in their experience crocodile numbers had decreased. They related the perceived decrease in the number of crocodiles to the longer drought periods in the area, the destruction of the crocodiles' natural habitats because of urbanization, poaching for meat and organs, and the lack of motivation from the stakeholders to undertake dam management for the conservation of ecosystem functions, including the protection of the crocodiles.

Although, as we have noted, many stakeholders think that the crocodiles are a problem, in all the three villages people seem to have a particular relationship with the

crocodiles. Respondents framed the crocodiles as lying at the heart of the APDs because, according to them, the availability of water depends on the crocodiles, because they maintain the water in the dams by digging holes so that the ground water can be reached. At Nikki and Sakabansi, crocodiles are considered wild animals but with the particular additional assumption that:

> *It is not good to kill crocodiles because this can bring misfortune* (farmer, Nikki, July 2009).

This assumption, however, does not prevent people from hunting the crocodiles, because they are thought to eat too much fish and because they are considered good bush meat. According to respondents in Nikki and Sakabansi the crocodiles also destroy fishing equipment and they attack their dogs and sometimes even their sheep. According to local press reports, in the period March 2010 to July 2011, two dogs at Nikki, four at Fombawi and six at Sakabansi were killed by crocodiles. In the same period, respondents stated that a child was bitten by a crocodile in Fombawi dam when it was swimming. Such incidents lead people to reason as follows:

> *We know that crocodiles are natural resources and part of our biodiversity. We have to protect them for new generations. In many villages, crocodiles disappear because of poaching. It is a pity for young people. In this village, we do not kill them all. We just kill adult crocodiles that cause damage and leave sub-adults and young animals in the dams to grow. We do not have any solution apart from killing them because they affect our means of living* (Farmer, Sakabansi, December 2009).

This analysis shows that there is an ambivalent attitude towards crocodiles: people do not feel comfortable about killing them; however, they do not want them in their dams. In Nikki we talked to a crocodile hunter who argued that God gave him the talent to fight the crocodile (which is considered to be extremely difficult) so that he was obliged to do so. This could be interpreted as a rationalization that allowed him to kill the crocodiles without taking the responsibility for doing so. At Fombawi, crocodiles are conserved for their specific role in the local culture: crocodiles are thought to be holy, protecting people from bad luck. Old people interviewed in Fombawi explained*:*

We have a great chance to have some specimens of crocodiles in our village and we thank God for that (CoGes member, Sakabansi, October 2009).

Neither killing crocodiles nor collecting them to give them away as pets is allowed in Fombawi. There is considerable local respect for the crocodiles and, as a result, most people have learned to peacefully live together with them by sharing fish and water. The rules and

behaviours for sharing are reinforced in celebrations and rituals and handed down to children in folk tales. Many people in Nikki and Sakabansi blame the people from Fombawi because they assume that the crocodiles present in their own dams have come from the Fombawi dam.

2.3.2 Stakeholders in government at different levels and in a non-governmental organization

In this section we explore the role of the governmental stakeholders and a non-governmental organization that is supporting the rational evolution in the use and management of the dams.

The council of Nikki represents the local government, following the decentralization reforms that started in 2005. The council consists of 17 town councillors elected by popular vote and the town councillors in turn elect the Mayor. The council employs workers to provide various services that impact the dams and their use. These workers, the councillors and the Mayor together form the staff of the council of Nikki.

In the decentralization process all the 20 APDs in Nikki District that were formerly under the control of the Communal Centre for Agriculture Promotion (CeCPA: *Centre Communal de Promotion Agricole*) are now under the control of the council. According to the Nikki council respondents, the income from fish production for all the 20 dams was estimated in total to be one million FCFA (€ 1527) in 2010 and 1.5 million FCFA (€ 2290) in 2011. This revenue should contribute to local development. The council's main interest is to raise more financial resources for local development by maximizing the dams' incomes, and to increase their power in decision making. However, the council has been blamed by the CoGes and users of the three dams for a prejudiced mismanagement of the dam income, giving use to a feeling of frustration amongst all the stakeholders. People reason as follows:
The Council of Nikki collects money from herders and they also sell fish. But they use the money for their own business (Herder, Sakabansi, November 2010).

CeCPA represents and provides a service at district level on behalf of the MAEP that consists of advising and helping farmers and herders in relation to various agricultural practices. Before decentralization, CeCPA managed the APDs. Nowadays, CeCPA only intervenes in dam management as an advisor. As stated by the workers interviewed, CeCPA's interest is to help to improve fish production in the dams and to advise users and managers on the sustainable management of the APDs. However, as noted in the field, co-operation between CeCPA and the Nikki council seems to be weak.

The department of forests and natural resources management (DGFRN: *Direction Générale des Forêts et Ressources Naturelles*) falls under to the Ministry of Environment, Housing and Town planning (MEHU: *Ministère de l'Environnement de l'Habitat et de l'Urbanisme*). At district level, the service is represented by a forester in charge of the preservation of natural resources (mainly fauna and flora). The forester explained that this service mainly assists in choosing valuable trees for the reforestation of the water edges and ecosystem rehabilitation. The forester always disagrees with the daily users, especially women who cut trees around the dams so as to use for cooking food, and the herders who allow the livestock to destroy the young trees.

The Participative Artisanal Fisheries Development Programme (PADPPA: *Programme d'Appui au Développement Participatif de la Pêche Artisanal*e) is a programme of the MAEP that is active around the Nikki and Sakabansi dams but not in Fombawi. The programme began working in 2005. Its activities include the reforestation of the water edges, stocking the dams with a total of 5000 young fish (*Oreochromis niloticus* and *Clarias. gariepinus*), donation of two fishing nets and two dugout canoes and training fishermen and vegetable growers.

PADPPA is helping the Nikki council in the design of a draft of a management plan for the two dams. Unfortunately, the programme ended in 2011 although the management plan for the dams was not yet implemented. The programme managers stressed that the programme's main interest was to find ways to harmonize three goals: (1) to improve fish production in the APDs, (2) to increase local people's income, and (3) to contribute to the sustainable use and management of the dams.

The Agricultural Engineering Service (DGR: Direction du Génie Rural) is a service of the MAEP and is in charge of the construction of the APDs and the monitoring and maintenance of the infrastructures. It advises the CoGes on how to carry out their tasks. According to the official staff interviewed, the budget for the maintenance of the dams is supposed to be financed by the money remaining from the initial construction fund. This money has been used and the service no longer has any money left so that the staff rarely visits the dams and maintenance of the infrastructure hardly takes place. As a result, all the dams are in a highly eroded condition.

The Netherlands Development Association (SNV) is a nongovernmental association that is providing considerable support to conflict management. It assists the APDs through the UCOPER and the farmer association by financing conflict-solving meetings and by training farmers and herders on local governance and conflict solving strategies. Its main interest is to

reduce farmer–herder conflicts and to promote sustainable agriculture. Our observations lead us to believe that the governmental stakeholders at both local and national level and SNV do not seem to be able to realize their ambitions, because of lack of sufficient cooperation with and co-ordination between the stakeholders they depend on to accomplish their own tasks and goals.

Table 2.2 summarizes stakeholders' main interests, the main impediments they perceive and the tensions that arise through dam use and management.

Most respondents perceive that it is the totality of activities that has resulted in the serious and continuous decrease in water quality and the persistence of the problems. They themselves perceive that the tensions and problems are likely to become worse since nobody feels responsible for taking action to change the existing situation.

2.4 Analysis and discussion

During the focus group meetings and the interviews with the various stakeholder groups the respondents frequently referred to both formal and informal rules related to the management and use of the dams. The formal laws that impact on the use and management of the dams are as follows:

1. Law 97-029, articles 84–107, on decentralization. Since 2005, administrative reform in Benin has been engaged in the implementation of processes of decentralization that aim to give local people the power to manage their own region. As a result, many issues have been left to local councils, such as environmental issues, hygiene, public health and rural infrastructure (including the bas-fonds, agro-pastoral dams, and ground water).
2. Law 2010-44 that relates to water management. It states that all the rivers and water holes including the APDs belong to the public domain. Articles 13 and 14 forbid all types of water pollution and article 57 allows for decrees to be issued concerning rules governing agricultural and pastoral activities.
3. Law 2002-016, relating to wildlife. It states that crocodiles are a fully protected species and should not be hunted.

As discussed above, the formal rules are not naturally respected at the local level and decentralization does not mean that local people are enabled to manage their environment; the water in the dams for instance is constantly polluted by the various and mostly daily activities.

The only village in which the crocodiles are protected is Fombawi and this is not because of the formal law but because of local beliefs and informal rules that fit these beliefs. A further distinction can be made between (1) informal rules set by the council, and (2) informal rules that are part of local cultures.

The following informal rules, presented in the results section, were set by the council:

- Anyone who wants to use water for house construction should pay 2000 FCFA (€ 3.05) per house;
- Transhumant herders are to pay 50 FCFA (€ 0.076) per animal before the animals are allowed to enter the area around a dam;
- Access to the dams from the dyke by humans and livestock is banned;
- Movement corridors are delimited and livestock should remain within the corridors when accessing the dams;
- Opening of farms within 1000 m from the edge of a dam is forbidden;
- Vegetable farming is authorized only downstream of the dams;
- It is forbidden to wash and swim in the dams;
- Washing is allowed only downstream of the dams;
- Vegetation fires may be lit only between 15 October and 30 November;
- Fishing is allowed only under the conditions and rules set by the Nikki council;
- The income from fish production is divided between the fishermen, the council and the dam management committee members; and
- Income from the dam is to be used for the purposes of local development.

These informal rules do appear to guide stakeholders' behaviour in the APDs to some extent. We note that they are well known by the dam users. However, this does not mean that they are automatically or universally obeyed.

The traditional rules constituted by Fombawi culture that require that crocodiles are treated in a respectful way include:

- Crocodiles are treated as sacred animals;
- Every year sacrifices are made to the sacred pond and crocodiles;
- It is forbidden to kill crocodiles in the Fombawi dam; and
- Any crocodile that dies is buried only after burial ceremonies headed and conducted by the traditional chief.

Table 2.2 Stakeholders' main interests, the main impediments they perceive and the tensions identified (To be continued)

N°	Stakeholders	Main interests	Main impediments perceived by stakeholders	Tension
1	Herders/UCOPER	Manage conflict between farmers Defence of herders' interests Improve water quality Involvement in the APD management UCOPER participates in the delimitation of national and international transhumance corridors	Recurrent conflict between farmers and herders Water pollution Silting up of dams	Blaming farmers for impeding access to the dams Blaming the Council of Nikki for taking a position favourable to the farmers Herders considered as strangers; their interests are not usually taken into account
2	Vegetable producers	Getting free access to dams	Decrease in vegetable yield Diseases and pests Lack of specific mineral fertilizer Lack of materials and seeds Destruction of garden fences by cattle Harassment in accessing credit Difficultly in accessing potential markets Low organization of vegetable producer associations	Tension with the Council of Nikki who want to expel them from their present location The Council of Nikki seen as a potential enemy
3	Non-vegetable farmers	Cropping in the surrounding of the APDs	Destruction of crop by cattle Conflict between farmers and herders Problem of land tenure	Tension with the Council of Nikki who decided to displace farmers farming in the radius of 1 Km from the APDs The Council of Nikki seen as a potential enemy
4	Daily users of the dams	Maintaining free access to the dams	Strong decrease in fish yield Silting of dams Increasing dryness Poor water quality Absence of attention to fish production Aquatic plant invasion Lack of fishing equipment Crocodile predation on valuable fish species	Tension with the Council of Nikki

Table 2.2 Stakeholders' main interests, the main impediments they perceive and the tensions identified (End)

N°	Stakeholders	Main interests	Main impediments perceived by stakeholders	Tension
6	Dam Management Committee (CoGes)	Participation in dam management	Not motivated to carry out their functions	Tension with the Council of Nikki
7	Crocodiles	Maintaining access to their habitat and food source in the dams	Poaching	Human-crocodile conflict in Nikki
8	Council of Nikki	Raising more financial resources for local development Maximization of dam income Increasing their power in decision making	Aquatic plant invasion Silting of dams Poor water quality Invasion of the dams by crocodiles	Tension with vegetable producers of Nikki Blamed by the CoGes and users Tension for a prejudiced mismanagement of the dam income Feeling of frustration among all the stakeholders
9	Communal Centre for Agriculture Promotion (CeCPA)	Advise and help farmers and herders in relation to various agricultural practices	Aquatic plant invasion Silting of dams Poor water quality Invasion of the dams by crocodiles	Tension with the Council of Nikki
10	Forests and Natural Resources Management Service (DGFRN)	Assist in choosing valuable trees for the reforestation of the water edge Contribute to ecosystem rehabilitation	Deforestation of the water edge Silting of dams Poaching of crocodiles	-
11	Participative Artisanal Fisheries Development Programme (PADPPA)	Improve fish production Increase local people's income Contribute to the sustainable use and management of the dams	Aquatic plant invasion Silting of dams Invasion of the dams by crocodiles	-
12	Agricultural Engineering Service (DGR)	Maintenance of the dam infrastructures	Silting of dams Destruction of the dam infrastructures	-
13	Netherlands Development Organization (SNV)	Reduce farmer-herder conflict Promote sustainable agriculture	Conflict between herders and farmers	-

When our respondents were asked why they do not always follow the formal and informal rules set by the council which they appear to know so well, they answered that they see no reason to do so since the council itself does not meet its promises. This seems to suggest that the notion of a societal contract is latent in people's minds, and that there is a preparedness to act differently only if there were mechanisms to ensure the contract was honoured. This suggests that more attention should be paid to how sanctions are structured and enforced. Since our findings show that the dams are used for multiple purposes, involving diverse practices and stakeholders' interests, backgrounds, knowledge, and assumptions, the creation of an effective regime would seem to require an active policy of negotiation that includes representatives who can legitimately 'speak for the crocodiles'.

Our results furthermore show that the use and management of the dams creates tension among the stakeholders, each of whom in effect treats the dams as an open access resource (Hardin, 1968), to reproduce their own 'truth' about who causes the tensions, and to shift the responsibility for conflict resolution to someone else.

The result of this institutional failure is a situation of 'collective irresponsibility' (te Velde et al., 2002). Meanwhile, the water is becoming seriously polluted and the dam infrastructure is deteriorating – problems that everyone recognizes. Everyone, however, is continuing to intensify exploitation because they receive a direct profit from their activities. Nobody feels guilty about their own contribution to damaging the dams and ecosystems. This might result in both planned and unplanned tipping points that could change the situation radically.

Experience from elsewhere suggests that the sustainability of the APDs would require someone to organize repeated interactions amongst a relatively small number of stakeholders able to develop institutions for monitoring and enforcing a degree of co-operation and that are regarded as legitimate by all stakeholders (Berkes et al., 2006; Vollan, 2008; Vollan and Ostrom, 2010; Ostrom, 2011). Researchers have identified 10 variables as positively or negatively affecting the likelihood of users' self-organizing to manage a resource such as the APDs: size of resource system, productivity of system, predictability of system dynamics, resource unit mobility, collective-choice rules, number of users, users' leadership/entrepreneurship, norms/social capital of users, knowledge of social–ecological system/mental models of users, and importance of resources for users (Wade, 1994; Ostrom et al., 1994; Baland and Platteau, 2000, Ostrom, 2009). All these variables are said to interact in a non-linear fashion (Ostrom, 2009). So the optimization of use of APDs should start from system thinking that takes into account stakeholders' views and actions, including how these

either strengthen or hinder each other, and addressing inter-dependent technical, social and institutional challenges. However, in the absence of strong awareness of the inter-dependency among stakeholders' interests, and their use of the dams, it is difficult to see how 'system thinking' might arise spontaneously.

2.5 Conclusions and implications for further studies

This study of the stakeholders and the rules of APD management in northern Benin provided insight into the variety of practices and perceptions of problems and impediments related to the use and management of dams in the Nikki District. From our results it can be concluded that the APDs are intensively used by animals, people and crocodiles, for diverse purposes. All stakeholders experience problems related to the use or management of the dams. These problems mainly have to do with access to the dams (for different purposes) and pollution of the water. An important outcome of our study is that the stakeholders involved put different and mostly mutually excluding interpretations on the causes, effects and solutions of the problems and on the impediments, and that there is no appreciation of their interdependency and no mutual accountability. As a result, multiple conflicts among stakeholders persist, with each one pointing to others for causing and thus for solving the problems. They present themselves as victims of the behaviour of others and this reinforces the tension between the stakeholders. This study also reveals that numerous formal and informal rules exist for managing and using the dams in the Nikki District. These rules, however, are differently interpreted and in many cases ignored. The formal rules are not taken into account by the users because according to them the council does not fulfil its promises and is not able to sanction those who ignore the rules. Also the informal rules that have been negotiated among council, dam managers and users are ignored, apparently also without consequences. In contrast, the informal rules concerning the treatment of crocodiles in Fombawi, that are based on strong internalized beliefs about the role of crocodiles in local Fombawi culture are respected, leading to peaceful co-existence with the crocodiles.

In order to deal with the problem of pollution and to organize a more peaceful and sustainable management and use of the APDs, a number of lines for follow-up research have emerged:

- Identifying a more efficient way to improve agro-pastoral dam water quality (by inviting stakeholders to assess the water quality, quantifying the various threats related to water

quality, documenting the local and scientific knowledge on water quality held by local stakeholders, and describing possible innovative solutions in relation to the identified threats);

- Developing an institutional mechanism through which to improve fish production (by identifying the biodiversity and productivity of fish in the agro-pastoral dams, how to couple fish production and crocodile conservation, and by developing a more detailed understanding of how crocodile behaviour and habitat use are framed by the stakeholders and of the role of endogenous knowledge, norms, values and beliefs about crocodile habitats and livelihoods);
- The characterization of crocodile behaviour and habitat use in agro-pastoral dams (by identifying the behavioural characteristics of the crocodiles, the conditions in which crocodiles share space with humans in a peaceful way, the triggering of the crocodiles' aggressiveness, the crocodiles species in the dams, and the impacts of crocodile behaviour patterns on human activities);
- The development and promotion of a more inclusive agro-pastoral dam management (by reviewing with stakeholders the technical and institutional constraints to constructive dam management and the roles of stakeholders in solving the technical and institutional constraints to this management).

CHAPTER 3

‘A pond with crocodiles never dries up’: a frame analysis of human–crocodile relationships in agro-pastoral dams in Northern Benin

G. Nathalie Kpéra[abcd], Noelle Aarts[be], Rigobert C. Tossou[f], Guy A. Mensah[d], Aliou Saïdou[g], Dansou K. Kossou[g], A. Brice Sinsin[c], Akke J. van der Zijpp[a]

[a] Animal Production Systems Group, Wageningen University, The Netherlands

[b] Strategic Communication Group, Wageningen University, The Netherlands

[c] Laboratoire d'Ecologie Appliquée, Faculté des Sciences Agronomiques, Université d'Abomey Calavi, Bénin

[d] Institut National des Recherches Agricoles du Bénin, Abomey Calavi, Bénin

[e] Amsterdam School for Communication Research, University of Amsterdam, Amsterdam, The Netherlands

[f] Département d'Economie, de Sociologie Anthropologique et de Communication, Faculté des Sciences Agronomiques, Université d'Abomey Calavi, Bénin

[g] Département Production Végétale, Faculté des Sciences Agronomiques, Université d'Abomey-Calavi, Bénin

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Abstract

Crocodiles, a protected species, share ecosystem services with local communities in agro-pastoral dams in Northern Benin. Using a comparative case study conducted in three villages and a framing perspective, this study aims to elucidate how stakeholders frame the presence of crocodiles, and how they use formal and informal institutions to deal with them. Respondents framed the presence of the crocodiles as problematic because of their negative effects on local livelihoods and people's tranquillity. Both causes and solutions are, however, framed differently in the three communities. Whereas in Nikki and Sakabansi, respondents seek solutions in changing the ecological environment, requiring others (the council, fishermen, and crocodiles) to change their behaviour, Fombawi respondents seek to adapt their own behaviour by respecting and applying traditional and practical rules for sharing their dam. Damage per crocodile is the highest in Nikki and the lowest in Fombawi, suggesting that the crocodiles in Nikki behave more aggressively than those in Fombawi. Further investigation is merited to determine whether or not crocodiles behave less aggressively when dealt with according to specific institutions. Intensive communication among stakeholders in the three villages is recommended to exchange experiences and ideas that may support a peaceful human–crocodile relationship inspired by existing institutional solutions.

Keywords: water resources management; human–crocodile interaction; framing; formal and informal rules; competing claims on natural resources

3.1 Introduction

To address the deterioration of the hydro-climate (Diop et al., 2009; Venot et al., 2012), West African governments have constructed dams to increase water storage capacity and regulate water courses. These agro-pastoral dams (APDs) have led to the extension of wetlands and favourable ecosystems (Bazin et al., 2011). The APDs are for public use and can thus be considered as a common good (Hardin, 1968; Ostrom, 2011). A diagnostic study carried out in Northern Benin (Kpéra et al., 2012) revealed that APDs are used for multiple purposes such as drinking water for livestock and people, fishing, vegetable growing, swimming, bathing, washing, road and house construction, food cropping, and cotton farming. The study

identified various stakeholders using the dams with different interests, knowledge, and opportunities, making APD management a complex and conflictive matter. Crocodiles (protected species) have made themselves at home in these APDs where they share space and resources (ecosystem services) with humans. Crocodiles are known to have positive effects on their environment as keystone species that maintain ecosystem structures and functions, including selective predation on fish and aquatic invertebrates, the recycling of nutrients, and the maintenance of wet refugia during periods of drought (Thorbjarnarson et al., 1992). However, the presence of crocodiles in the APDs adds a dimension of human–wildlife conflict to the already complex situation. People who use the APDs have seen their water resources jeopardized by the crocodiles preying on fish and livestock, destroying fishing equipment and dam infrastructures, and injuring people (Kpéra and Sinsin, 2010; Kpéra et al., 2012).

Human–wildlife conflict is a global concern and a critical threat to the existence of several endangered species such as lions, crocodiles, leopards, bears, elephants, and so forth, as well as human beings (Lamarque et al., 2009; Bhattacharjee and Parthasarathy, 2013). Human–wildlife conflicts occur when the requirements of wildlife overlap with those of human populations. Conflicts are more intense in areas where both human populations and wildlife live and share ecosystem services. The implications of conflicts are manifold, ranging from psychological manifestations, such as fear, right up to fatal attacks (Bhattacharjee and Parthasarathy, 2013; Jhamvar-Shingote and Schuett, 2013).

Because of crocodiles' international and national endangered status (Kpéra et al., 2011, International Union for Nature Conservation (IUCN) 2012) and their role as keystone species (Mazzotti et al., 2008; Fujisaki et al., 2012), the improvement of APD management should address the human–crocodile relationships in such a way that both humans and crocodiles can benefit from the diverse APD ecosystem functions. Improving APD management entails changes that would allow stakeholders to live in peace with crocodiles and thereby improve their livelihoods. These stakeholders may diverge substantially in how they define what is at stake (Dewulf et al., 2005).

The aim of our study is to sharpen our understanding of:

(1) How stakeholders in different communities frame the presence of crocodiles in terms of problems and solutions;

(2) The formal and informal institutions they use to deal with crocodiles, and

(3) What this means for their relationship with the crocodiles.

Section 3.2 outlines the research approach based on a conceptual elaboration of frames and framing, institutions, and change. The research setting and methods of data collection and analysis are described in the methodology section. The results section presents stakeholders' framing of problems relating to the existence of crocodiles in the APDs, including the framing of causes and solutions. The formal and informal rules people use to deal with the crocodiles are also presented. It is shown that stakeholders in the different communities frame problems and solutions differently, refer to different kinds of formal and informal institutions, and consequently deal with crocodiles in different – more or less – peaceful ways.

3.2 Conceptual framework

To examine human–crocodile relationships, we developed a conceptual framework starting from three inter-related concepts: frames and framing, institutions, and institutional change.

3.2.1 Frames and framing

A main starting point of our research is the idea that realities are constructed through communication among people (Gray, 2003; Aarts and van Woerkum, 2006; Dewulf et al., 2009). As problems are created by individuals and groups in society, a multiplicity of perspectives on these problems – including their causes – and possible solutions may exist, and thus a frame-reflective approach may be an appropriate mechanism to deal with them (Rein and Schön, 1996). Framing has to do with making sense, interpreting, and giving meaning to what is happening in the ongoing world (Weick, 1995). Frames are structured, shared ways of speaking, thinking, interpreting, and (re)presenting social realities in the world (Webler et al., 2001). Entman (1993, p. 52) argued that framing means selecting 'some aspects of a perceived reality and making them more salient in a communicating context, in such a way as to promote a particular problem definition, causal interpretation, moral evaluation, and/or treatment recommendation for the item described. As Yanow (2000, p. 11) explained: 'That which is highlighted or included is often that which the framing group values.' Consequently, the framing of a problem is the result of processes of interaction and negotiations between different actors (Idrissou et al., 2011a; van Lieshout et al., 2012). Stakeholders involved in APDs thus are likely to construct realities in interactions by using specific frames relating to the presence of crocodiles.

To explain human–crocodile relationships, we focused on the framing of the issue at stake and the relationships involved. Issue frames reflect the meanings attached to events, phenomena, or problems in the relevant domain or context. Issue frames may contain problem, cause, and solution frames – in this case relating to humans and crocodiles sharing a dam – and are constructed to define the causes of problems as well as solutions for living together. When talking about the issue at stake, stakeholders disclose their own identities and their characterizations of others in their expressions. Identity frames are statements about one's own identity in relation to the problem at stake (Gray, 2003). These frames are expressed in interaction and are the answers to the questions: Who am I? and What is my role? Individuals may, for instance, frame themselves as champions of a particular cause or as victims of others' actions or policies (Dewulf et al., 2009). Characterization frames are statements about 'the other, who may be an individual or a specific group (Gray, 2003). Stakeholders rely on characterization frames as shorthand ways of describing people and making judgements about them (Shmueli et al., 2006). In the case of human–crocodile relationships, characterization frames are expressions about crocodiles and about other stakeholders who may affect human–crocodile relationships.

3.2.2 Institutions and institutional change

By institutions, we mean the informal and formal rules and regulations that govern human interaction (North, 1990; Hounkonnou et al., 2012). Woodhill (2008) described institutions as formal and informal rules that enable and structure all forms of social interaction and create stability and order in society. Institutions may include different forms of organization, regular patterns of behaviour, language, laws, customs, beliefs, and values.

The involvement of many interdependent stakeholders in the management of APDs poses numerous challenges for those interested in inducing change in the complex problem situation (Aarts and van Woerkum, 2006). Therefore, barriers need to be crossed, and bridges need to be built among different human stakeholders (characterized by different identities, interests, cultures, and beliefs) and – in this case – between human and non-human stakeholders (crocodiles). The space for meaningful change is regularly inhibited by the fact that many organizations, institutional arrangements, networks, and actors (including those at higher levels) are involved (Aarts and van Woerkum, 2006; Idrissou et al., 2011b). When such constraints are removed, lifted, or transformed, space for change may emerge (Leeuwis and Aarts, 2011; Hounkonnou et al., 2012). Framing dynamics in the interactions among and

between stakeholder communities may play decisive roles for constructing such space (Ford and Ford, 1995).

3.3 Methodology

3.3.1 Research area

The research area covers the local communities living around three APDs (Nikki, Sakabansi, and Fombawi) in Nikki District in Borgou Department located in north-eastern Benin.

Covering an area of 3171 km^2 and lying between 9856′ 2N and 3812′ 16E, Nikki District has 20 APDs constructed by the national government as watering holes for local, national, and international livestock, and for agricultural sector development. These infrastructures aim to enhance users' incomes by improving and supporting agricultural production (Capo-Chichi et al., 2009). Local communities engage mainly in mixed crop–livestock farming, herding, fishing, and earn a cash income from trading their produce. To grow their crops and livestock, they use water from the dams. In addition, the water is used for fishing, washing, and swimming.

The APDs in the villages Nikki, Sakabansi, and Fombawi were selected because they differ in terms of numbers of crocodiles that live in and near the dams and in terms of local traditions and beliefs of the people who use the dams. At the same time, the villages are comparable in terms of location (all in Nikki District), types of livelihood supports, and the diversity of stakeholders. The local stakeholders involved in the dams not only differ in the way in which they make use of the dam, they also practice different religions – Animism, Islam, and Christianity – and belong to different ethnic groups. Local and transhumant herders, for instance, belong to the Peul ethnic group, whereas the other stakeholders are of mixed ethnicity. Table 3.1 summarizes the main features of the three APDs (Capo-Chichi et al., 2009; Kpéra et al., 2012).

3.3.2 Case study design

Case studies enable the development of richly textured information that can be used to explain complex patterns and correlations, causal links in real-life situations, and to describe the real-life context in which interventions take place. They allow for analytical generalization rather

than statistical generalization, meaning that previously developed theory is used as a template against which to compare the empirical results of the case study (Yin, 2002; Thatcher, 2006). A comparative case study approach was used as the overarching research design of this study.

Table 3.2 Problem and cause frames relating to living with crocodiles as constructed by the stakeholders in the agro-pastoral dams

Villages	Problem frames	Cause frames
Nikki	- Fear of crocodiles - Aggressiveness of crocodiles - Attacks on livestock and dogs - Predation on valuable fish - Damage to fishing equipment - Digging holes in the dykes	- Illegal hunting of crocodiles - Human population growth - Deforestation around the dams - Food shortage for crocodiles during the dry season - Crocodiles and dogs are enemies - Water pollution
Sakabansi	- Fear of crocodiles - Predation on valuable fish - Attacks on livestock and dogs - Destruction of fishing nets - Damage to fishing equipment - Digging holes in the dykes - Injuries to children	- Large specimens - People's negative behaviour towards crocodiles - Illegal hunting of crocodiles - Fishermen's selfishness - Incompatibility between fish farming and crocodile conservation
Fombawi	- Injuries to children - Predation on fish species - Attacks on livestock and dogs - Digging holes in the dykes	- Non-respect of traditional rules relating to crocodiles

The case study method is suitable for this research because we are trying to illuminate a phenomenon in its natural setting using multiple data collection methods to gather information from one or a few entities (people, groups, and organizations) (Eisendhardt, 1989). The comparative aspect of the case study facilitates a better understanding of how and why three communities act differently in broadly similar circumstances.

3.3.3 Data collection and analysis

Data were collected from 2009 to 2012 through interviews and informal talks with 107 respondents in the three villages, using an interview guide. The respondents consist of members of dam management committees (CoGes), local herders, transhumant herders, vegetable growers, farmers, daily users of the APDs, fishermen, members of Nikki Council, children, and members of the Centre for Agriculture Promotion (CeCPA), of the Forests and Natural Resources Service (DGFRN), and of the Participative Artisanal Fisheries Development Programme (PADPPA). In addition, 13 focus group discussions (FGDs) were conducted with members drawn from each of the stakeholder categories identified in the three villages (yielding four FGDs in Nikki, five in Sakabansi, and four in Fombawi). The FGD participants included farmers, vegetable growers, herders, dam management committee members, Nikki Council, children who swim in the dams, daily women users of the APDs, and people who worship crocodiles. The participants (interviews and FGDs) were selected using a snowball technique (Biernacki and Waldford, 1981) guided by the criteria that they (1) have a stake in the issue and (2) differ as much as possible in gender, age, and occupation. Each respondent giving a reply in one of the villages was counted as one. All interviews were tape-recorded, transcribed, translated into French (the native language of the researcher), and then translated into English. Finally, policy documents relating to APD management in Nikki Council were studied.

The analysis started with various rounds of intensively reading of text with the aim of identifying problem, cause, solution, identity, and characterization frames, as well as frames referring to formal and/or informal institutions. Next, we looked for patterns of specific frames that were repeatedly expressed. Finally, specific frames were selected as most illustrative of the patterns found. The data were analysed using discourse analysis methods (Hodges et al., 2008). Discourse analysis considers that using language is a form of action (Hammersley, 2003): when people talk, they not only represent realities, but also create realities (Ford, 1999; Te Molder and Potter, 2005). Discourse analysis methods create sensitivity for the way people construct credibility in interaction, by naming, blaming, and – in many cases implicitly –showing who they think is accountable at a certain juncture.

3.4 Results

3.4.1 Framing problems and causes

When people were asked for their personal experiences with crocodiles, they all were eager to share them. Table 3.2 summarizes the problem frames as constructed by the respondents at the Nikki, Sakabansi, and Fombawi APDs.

Table 3.2 Problem and cause frames relating to living with crocodiles as constructed by the stakeholders in the agro-pastoral dams

Villages	Problem frames	Cause frames
Nikki	- Fear of crocodiles - Aggressiveness of crocodiles - Attacks on livestock and dogs - Predation on valuable fish - Damage to fishing equipment - Digging holes in the dykes	- Illegal hunting of crocodiles - Human population growth - Deforestation around the dams - Food shortage for crocodiles during the dry season - Crocodiles and dogs are enemies - Water pollution
Sakabansi	- Fear of crocodiles - Predation on valuable fish - Attacks on livestock and dogs - Destruction of fishing nets - Damage to fishing equipment - Digging holes in the dykes - Injuries to children	- Large specimens - People's negative behaviour towards crocodiles - Illegal hunting of crocodiles - Fishermen's selfishness - Incompatibility between fish farming and crocodile conservation
Fombawi	- Injuries to children - Predation on fish species - Attacks on livestock and dogs - Digging holes in the dykes	- Non-respect of traditional rules relating to crocodiles

3.4.1.1 Blaming crocodiles

All respondents in the interviews and the FGDs initially framed crocodiles in a negative way. In Nikki, Sakabansi, and Fombawi, the respondents agreed that crocodiles prey on fish, damage fishing equipment, attack dogs, sheep, and goats, and dig holes in the dykes. Fishermen complained about crocodiles because they adversely affected their livelihoods, as highlighted in the next statement:

> *They destroy our fishing nets and eat big size fish species. They eat the bodies of the fish and leave the heads for us. In addition, they dig holes in the dyke, destabilising the dam infrastructure.* (Fisherman, Nikki 2011).

A closer examination of this statement reveals several identity and characterization frames. The fishermen presented themselves as ultimate victims of the situation while blaming the crocodiles.

Herders who regularly visit dams to drench their flocks of cattle, sheep, and goats expressed similar worries about crocodiles, as illustrated by the secretary of the herders' association:

> *Crocodiles are becoming more and more aggressive. They attack and eat our sheep and goats. I suppose that the next step will be the attack of our cattle, and why not the herders?* (Local herder, Nikki 2010).

In addition to the problems mentioned above, in Nikki and Sakabansi people expressed worries about crocodiles because of their aggressiveness and the fear they instil. All women who use the dams on a daily basis and the vegetable growers we met at the two dams claimed that crocodiles were a serious problem:

> *We fear them. Six people died in the dam when they were swimming, and their deaths have been attributed to crocodiles that may have drowned their victims.* (Housewife, Nikki 2010)

Interestingly, the latter part of this quote indicates a more careful and less explicit blaming of the crocodiles.

According to the daily women users of the Sakabansi dam, the dam contains more than a hundred – mainly big specimen – crocodiles. Similar to respondents from Nikki, they considered the presence of the crocodiles as problematic:

> *There are many big crocodiles in the water. They attack and kill our dogs and small ruminants when they come to drink. This happens mainly during the dry season. Often crocodiles bite people when they are swimming in the dam. Besides, they fight among themselves, and this reaction makes people fearful.* (A daily user, Sakabansi 2010)

Credibility is often constructed with reference to a personal experience, as is the case in the following quote:

> *……..One day, when I was collecting water, a crocodile pulled my bowl out of my hands and plunged into the water. I ran away*. (A daily user, Sakabansi 2010)

In all these testimonies, the crocodiles are blamed for the problems that people experience because of the presence of crocodiles in the APDs.

3.4.1.2 Blaming people

It was not only crocodiles that were blamed; human behaviour towards crocodiles was also criticized.

In the next quote, for instance, the fishermen are blamed for the situation:

> *When fishermen come to fish, they collect all the big fish species from the dam so that crocodiles cannot find food and start killing our livestock. Conflicts then arise between humans and crocodiles.* (A daily user, Sakabansi 2012).

In Fombawi, one of the women who regularly clean shea butter nuts at the water's edge blamed people who neglected the rules and thus created a problematic relationship with crocodiles:

> *Crocodiles have been living in this village for many generations. Our grandfather told us that his own grandfather was not able to tell him when they came to the village. They roamed in the village like sheep and goats, and they never attacked either people or livestock. In turn, people did not kill them because they are sacred animals. Today, although crocodiles remain holy, they attack village dogs, sheep, and goats that come to drink in the dam. Crocodiles also bite children when they are swimming. They become aggressive because people, mainly young people, do not respect the traditional rules relating to the sacred crocodiles. When we reprimand them, they don't even listen to us.* (Woman daily user of the APD, Fombawi 2010)

Implicitly, the speaker identified herself and the other women as the ones who knew what should be done (i.e. follow the traditional rules).

Interestingly, in Fombawi, a fisherman, who in Nikki had framed crocodiles as a bottleneck for fish farming, extensively explained how peacefully crocodiles can be dealt with when their holiness is respected:

> *Although there are many crocodiles, fishing parties are easy for us because of the collaboration of the local communities with the crocodiles. ……. Before we start fishing, the head of the village prays and requests the holy crocodiles to allow us to fish. After the praying, crocodiles leave the dam and run into their holes located in the vegetation and into the dyke. We then start fishing. Young crocodiles, however, are sometimes caught in our nets, and we return them into the water after fishing.* (Fisherman, Nikki 2011).

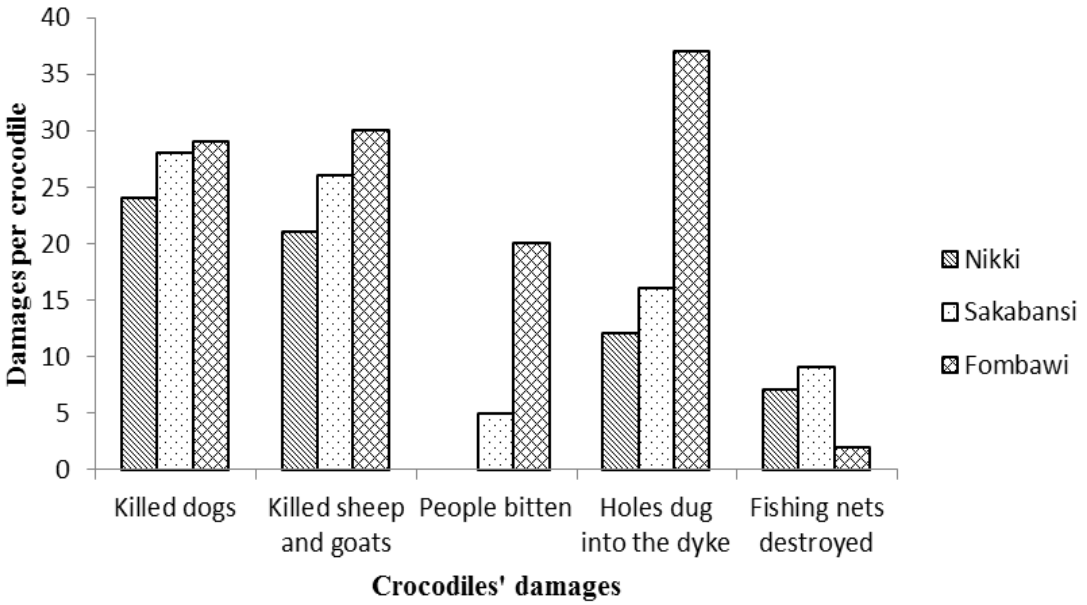

Figure 3.1 Number of different types of damage caused by all the crocodiles in Nikki, Sakabansi, and Fombawi dams from August 2009 to December 2012

Both the praying activity and the habit of throwing back into the water young crocodiles caught by accident are informal institutions that are apparently collectively agreed upon in Fombawi. The fact that these rules were articulated only in Fombawi shows the relevance of context to the construction of specific frames.

To show the relation between frames and the context in which they are constructed, Figure 3.1 presents the incidences caused by crocodiles in the three APDs from 2009 to 2013. This figure shows that, besides similarities, there are also differences. Apart from the fact that

nobody seems to be bitten by crocodiles in Nikki, the number of other kinds of incidences is generally higher there than in Sakabansi and Fombawi.

At first sight, the number of fishing nets destroyed is lowest in Fombawi (Figure 3.1), which has more crocodiles (300) than Sakabansi (100) and Nikki (20). It may be that praying before fishing is effective. The high number of crocodile holes in Fombawi APD is in line with the relatively high number of crocodiles and the proximity of the dam to the village. In addition, some people from Nikki intimated that six people may have been drowned by crocodiles, although from 2009 to 2012 there is no record of people being killed or bitten.

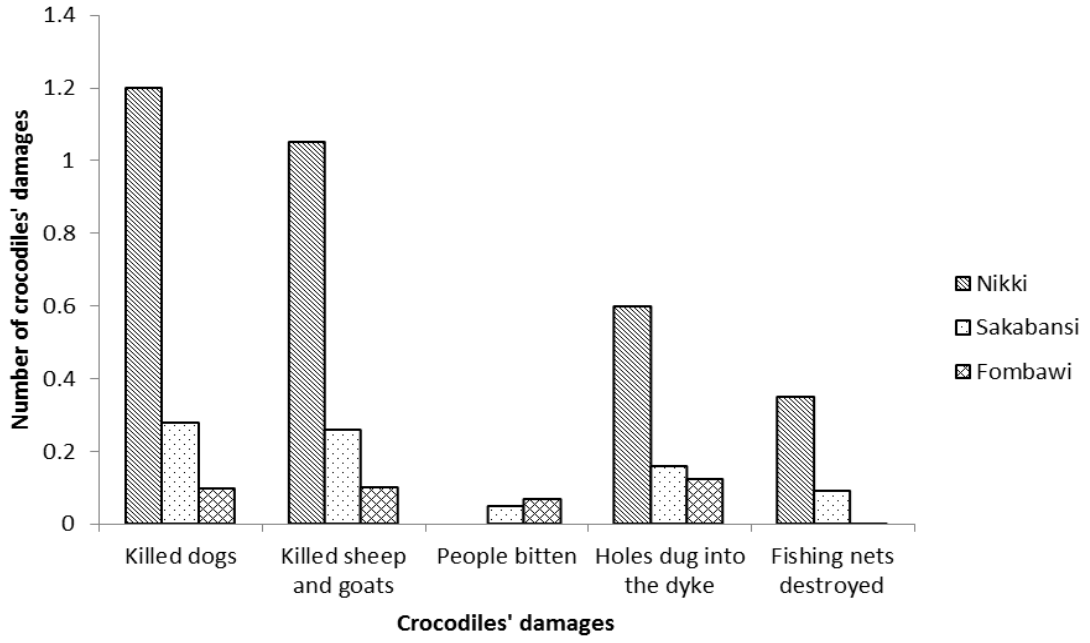

Figure 3.2 Number of different types of damage caused per crocodile in Nikki, Sakabansi, and Fombawi dams from August 2009 to December 2012

The absolute damage caused by crocodiles is higher in Fombawi; however, as there are more crocodiles, the relative amount of damage per crocodile (Figure 3.2) is lower. This may imply that the crocodiles in Fombawi are less aggressive than in Nikki and Sakabansi, and/or that the Fombawi inhabitants are more tolerant towards crocodiles.

To summarize, respondents experience similar problems in the three villages but with different intensities, and they frame the causes differently. Problems between humans and crocodiles as framed by stakeholders in the three villages are attributed to crocodiles (through

damage that they caused) and to stakeholders' behaviours (fishermen's 'selfishness'; non-compliance with traditional rules).

3.4.2 The role of institutions

In this section, we present the way respondents refer to formal (written) and informal (unwritten) institutions relating to crocodiles.

3.4.2.1 The role of formal institutions

Formal institutions for protecting crocodiles have been formulated at both national and international level (Table 3.3).
Apart from the respondents from the DGFRN and from the PADPPA who acknowledged these international rules and indicated that communities have been informed about them, stakeholders expressed unawareness of these formal rules, as illustrated by the next quote:

> *We don't know the specific content of these rules about wild animals*. (Farmer, Nikki 2012).

Although some respondents expressed ignorance of formal regulations, according to others, they know perfectly well that crocodile species are protected and should not be killed.

> *Everybody in the village knows that crocodiles are protected by the State of Benin. However, they kill them. If you go to the market, you will see all the products and body parts of the animal for sale* (Dam users, Nikki 2011).

One of the respondents showed awareness of the formal regulations by explicitly contesting the rule that crocodiles should be protected:

> *We are living with a carnivore that can kill humans at any time. For me, the law is incomplete because it should also say what to do in the case of damage and attacks on people* (Vegetable producer, Sakabansi 2012).

Interestingly, instead of referring to the formal protection rules, several respondents referred to another factor that supports the protection of crocodiles, namely, the low prices offered for crocodile leather, which discourages people from killing crocodiles, thus contributing to the increase in the number of crocodiles invading the dams:

Table 3.3 Different formal institutions at international and national level relating to human–crocodile relationships

Level	Formal institutions	Content of the rules
International level	Convention on Biological Diversity (CBD)	- Goals: conservation of biodiversity, sustainable use of biodiversity, fair and equitable sharing of the benefits arising from the use of genetic resources
	Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES)	- Goals: to ensure that international trade in specimens of wild animals and plants does not threaten their survival - The CITES convention does not allow the trade of skins of Benin crocodile species
	IUCN Red List of African crocodile species	- The most comprehensive information source on the status of wild species and their links to livelihoods. The IUCN Red List of Threatened Species Version 2012.1 classed *Crocodylus niloticus* as lower risk/least concern, *Oesteolaemus tretraspis* as vulnerable, and *Mecistops cataphractus* as data deficient
National level	Law N°97-029, article 84107, on decentralisation in Benin	- From 2005 onwards, decentralisation that gives local people the power to manage their own region, Nikki council has the right to manage all the agro-pastoral dams in Nikki District - The incomes generated by these infrastructures should serve local development
	Law N°2010-44 relative to water management in Benin	- All the rivers and water holes, including the APDs, belong to the public domain. Articles 13–14 forbid all types of water pollution and article 57 allows for decrees to be issued concerning rules governing agricultural and pastoral activities
	Law N°2002-016 relative to wildlife management in Benin	- Crocodiles are a fully protected species and should not be hunted
	Red List for Benin	- In 2011, scientists designed at national level a Red List of Threatened Species. The Nile crocodile (*Crocodylus niloticus*) is classed as Vulnerable (VU), the African dwarf crocodile (*Oesteolaemus tretraspis*) as Endangered, and the African Slender-snouted Crocodile (*Mecistops cataphractus*) as Critically Endangered (CR)

> *Before coming to Nikki, I fished and hunted crocodiles in the Niger River on both the Benin and Niger side. At that time, one could earn 50,000 to 100,000 FCFA (Franc-Financial Community of Africa, Franc- Communaute´ Financière d'Afrique) (€ 76.30 to €152.60) depending on the size of the animal. Because of the fall in the international price of leather, we have all abandoned the activity….. If the price of crocodile skin was still high, you would not see any crocodiles in agro-pastoral dams. Those who kill them here do it for meat and some body parts that are used in traditional medicine*. (Fisherman, Nikki 2012).

3.4.2.2 The role of informal institutions

Informal institutions consist of (1) rules set by Nikki Council about the management of the APDs, (2) common beliefs relating to crocodiles, and (3) traditional rules relating to the sacred crocodiles in Fombawi. These rules have not been written down, but instead developed and kept alive by people constantly communicating and applying them. Informal institutions, as articulated by the respondents, are presented in Table 3.4.

The APD management rules set by Nikki Council focus on the way activities should be carried out in/around the dams and their surroundings and on the main functions of the CoGes (dam management). We noted from the interviews that these rules were well known by the dam users, but this does not mean that they are automatically or universally obeyed. They appear to guide stakeholders' behaviour in the APDs to some extent. As given in Table 3.4, crocodiles are not mentioned in the rules, neither are sanctions that people will face if they do not respect the rules.

A belief shared by all respondents in the three villages is that 'The crocodile is the heart of the water. A pond with crocodiles never dries up' (Respondents in Nikki, Sakabansi, and Fombawi 2010). This shows that people associate the presence of crocodiles with a healthy dam ecosystem. The belief should thus prevent the killing of crocodiles in the three villages if people want to maintain water in the dams.

Traditional rules that support living peacefully together with the crocodiles, based on the belief that crocodiles are sacred creatures, were articulated only in Fombawi (Table 4). According to the respondents, most people in Fombawi, even those belonging to different religions, respected these rules:

Table 3.4 Different informal institutions at Nikki District level relating to APD management and to human–crocodile relationships

Level	Informal institutions	Content of the rules
Nikki District level	Rules set by Nikki council relative to the management of the APDs	- Fees for the use of the APDs: house construction 2,000 F CFA (€ 3.04) per house; transhumant herders: 50 F CFA (€ 0.07) per animal - Access to the dams from the dyke by humans and livestock is banned - Movement corridors are identified and livestock should remain within the corridors to access the dams - Establishment of farms within 1,000 m of the edge of a dam is forbidden - Vegetable production and washing are authorised only downstream of the dams - It is forbidden swim in the dams - Vegetation fires may be lit only from October 15 to November 30 - Fishing is allowed only under the conditions and rules set by the town council - The income from fish farming is divided between the fishermen, the town council, and the dam management committee members (CoGes: Comité de Gestion du barrage) - Income from the dam is to be used for local development - The CoGes members are selected by Nikki council at a general assembly and its main functions are to clean periodically the dams and the surrounding area, open transhumance corridors, prevent robbery of the fish, and control activities that contribute to the silting up of the dams and to water pollution – The CoGes should take care of the dams and in compensation benefit from a recompense (amounting to 2/3 of the fish farming per fishing session)
Nikki, Sakabansi, and Fombawi village level	Common belief relative to crocodiles	'The crocodile is the heart of the water'
Fombawi village level	Traditional rules relative to sacred crocodiles in Fombawi	- Crocodiles are treated as sacred animals and should not be killed - Every year sacrifices must be made to the sacred pond and the crocodiles, and every household must prepare food and bring it as a sacrifice - Before carrying out any activity at the dam, people must ask crocodiles for permission - Any crocodile that dies is buried only after burial ceremonies, headed by the traditional chief - Any woman in menses does not have the right to collect water from the dam

> *Crocodiles were living in a small pond located 80 m from the dam. They invaded the dam because of the presence of fish and the large water area. They are the protectors of our village, and annually all the inhabitants of the village go to the pond to fulfil one of the rules: the sacrifice to the sacred pond and the holy crocodiles. The village head is the one who leads praying at the pond. Furthermore, when one has particular intentions, one can go and see the traditional chief who will conduct you to the pond for sacrifices, and it works*. (Dam user, Fombawi 2010).

It can be concluded that most respondents are aware of the key message of national and international regulations and laws, which is that killing crocodiles is forbidden. In Fombawi, informal institutions were constructed and respected to live peacefully with the crocodiles. In Nikki and Sakabansi, the killing of crocodiles was made acceptable by means of rhetorical devices, as given in the next section.

3.4.3 Framing solutions

Table 3.5 summarizes the solution frames for living with crocodiles as constructed by the respondents.

Two kinds of solution to the problem can be identified from the interviews: (1) changing the ecological environment and (2) changing institutions.

3.4.3.1. Changing the ecological environment

Killing crocodiles has been mentioned as a solution to the problem, especially in Nikki and in Sakabansi. This entails finding ways to cope with cognitive dissonance because people know that killing crocodiles is prohibited. Such is reflected in the following quote of a former crocodile hunter in Nikki, who shifts responsibility for killing crocodiles to God who gave him the talent to kill:

> *I can't count the number of crocodiles I killed in my life. When God gives you a talent to do something, you should use it as you want.* (Former crocodile hunter, Nikki, November 2010)

Table 3.5 Solution frames relating to living with crocodiles as constructed by the stakeholders in the agro-pastoral dams

Villages	Solution frames
Nikki	- Collect and cage all the crocodiles for tourism - Make clear rules and regulations relating to dam use - Killing of crocodiles (hidden solution)
Sakabansi	- Fishermen should leave some fish for crocodiles - Nikki council should give compensation to those whose livestock and dogs are killed by crocodiles - Kill them (hidden solution) - Collective action: weekly livestock market provides income for regular cleaning/upkeep of the dam
Fombawi	- Swim in groups - Praying, communicating with the crocodiles, and other ceremonies - Regularly remind people about the traditional rules

The oldest and main fisherman in Sakabansi confessed:

> *We know that crocodiles are natural resources. We have to protect them for new generations. In many villages, crocodiles are disappearing because of poaching. In this village, we just shoot adult crocodiles that cause damage and leave sub-adults and young animals. We do not have any solution apart from killing them because they affect our livelihood.* (Fisherman, Sakabansi, December 2009).

This quotation also shows an ambivalent attitude towards crocodiles: on the one hand, fishermen in Sakabansi do not feel comfortable about killing crocodiles; on the other hand, they do not want them in their dams.

In Nikki, several daily dam users, as well as members of the Nikki dam CoGes, suggested ecological solutions relating to a new dam design, to be carried out by Nikki Council:

> *A new dam with a fence should be constructed and all the crocodiles infesting our dams will be parked there. This place will serve for tourism based on crocodiles. This new activity should bring money to the whole district*. (CoGes member, FGD, Nikki 2010)

In Sakabansi, women daily users of the Sakabansi dam suggested reorganizing the accessibility of the dam:

> *To avoid any attack and fear caused by crocodiles, it is necessary to have only one entrance to the dam. Furthermore, each type of activity carried out around the dam should have a particular place depending on its effect on water quality.* (Housewife, Sakabansi 2011).

Fishermen in Sakabansi suggested a technological solution, as illustrated by the following quotation:

> *The PADPPA offered two floating cages and 5000 small fish to promote fish farming in Nikki. If we can find a project that will help us to install a floating cage for fish production in Sakabansi, this will largely prevent crocodile predation on our fish species and increase our income.* (Fisherman, Sakabansi 2011).

Local herders in Nikki and Sakabansi complained about the fishermen, as they framed their behaviour as the main cause of the problem:

> *Fishermen should not catch all big fish species. They should leave some to crocodiles as food. Then, the crocodiles would not attack our livestock.* (Herder, Sakabansi 2011).

3.4.3.2. Changing institutions

In addition to solutions that relate to changing the ecological environment, suggestions were made to change institutions, for instance to change formal rules by introducing monetary compensation:

> *Since the council sells fish from dams and collects money from transhumant herders and from those who use water for road and house construction, it should give compensation to herders whose livestock have been killed by crocodiles.* (Local herder, Nikki 2012)

And:

> *The employment of a security guard by Nikki Council, which is the manager of the dam, should oblige people to respect rules relating to the use of the dam and prevent them messing around.* (Housewife, Sakabansi 2011)

In both solutions, Nikki Council is framed as being responsible for developing new rules, as well for ensuring that people will not ignore them.

In contrast to Nikki and Sakabansi, the Fombawi respondents framed the solution to the problem as the construction and application of rules that ensure a peaceful relationship with the crocodiles. During one of the FGDs, female vegetable growers suggested:

> *When people strictly respected traditional rules, crocodiles did not attack either livestock or humans. Why not return to strict respect for these rules?* (Vegetable grower, Fombawi 2012)

Children added practical rules that they apply when swimming:

> *Crocodiles attack people when they swim alone. Therefore we swim in a group and avoid going into the middle of the dam, which is the deepest part. We also make a lot of noise to move crocodiles away from us*. (Children bitten by crocodiles, Fombawi 2012)

Whereas the respondents from Nikki and Sakabansi preferred changing the ecological environment, the Fombawi respondents suggested changing informal institutions to allow peaceful co-existence with crocodiles. Another striking difference concerns who should be responsible for solving the problem. In Nikki and Sakabansi, the solutions suggested by the respondents shifted responsibility to the council. The Fombawi respondents stated that they themselves should take the responsibility for dealing peacefully with crocodiles by respecting supporting institutions, which have been ignored for a long time.

3.5 Discussion

Our study revealed that the respondents in the three villages framed the presence of the crocodiles as a problem because of their negative effects on local livelihoods and people's tranquillity. Both causes and solutions were, however, framed differently in the three communities. This shows the relevance of specific contexts for the development of shared knowledge, rules, and behaviours. In Nikki and Sakabansi, the causes of the problems revolved mainly around blaming both crocodiles and other stakeholders involved in the dam. To solve the problems, respondents in Nikki suggested separating the crocodiles into their own dam and letting them play a role in tourism (Table 3.5). Another solution was to construct legitimacy to kill crocodiles (Table 3.5) – a solution that is, however, contrary to national and international regulation (IUCN, 2012) and thus generates uncomfortable feelings among respondents. The third solution mentioned by the Nikki respondents was to make clear

rules and regulations relating to dam management. In Sakabansi, respondents suggested that fishermen should leave some fish for the crocodiles, that Nikki Council should compensate those whose livestock and dogs were killed by crocodiles, and that big and aggressive crocodiles should be killed (Table 3.5).

Although Fombawi respondents experienced similar problems, their solutions were quite different. Whereas in Nikki and Sakabansi, stakeholders seek solutions in changing the ecological environment, which requires others (the council, fishermen, and crocodiles) to change their behaviour, people in Fombawi seek to change their own behaviour by respecting and applying traditional and practical rules for peacefully sharing the dam with crocodiles. Examples of such rules are praying and similar ceremonies, and communicating with the crocodiles. Interestingly, the research shows that the damage per crocodile is the highest in Nikki and the lowest in Fombawi, suggesting that the crocodiles in Nikki behave more aggressively than those in Fombawi. Further investigation is merited to determine whether or not crocodiles indeed behave less aggressively when dealt with in specific ways, as is the case in Fombawi.

The different solution frames articulated by respondents are worthy of further exploration and discussion. The idea of financial compensation for crocodile attack victims is a general solution proposed by wildlife managers in Africa, as indicated by Lamarque et al., (2009). However, Lucherini and Merino (2008) and Bhattacharjee and Parthasarathy (2013) have suggested that financial compensation can weaken conservation efforts, leading to retaliatory killing of wild animals that threaten local people's livelihoods.

The belief-related solutions in Fombawi reflect the important role of institutions that relate to human behaviour towards crocodiles, in combination with specific knowledge about crocodile behaviour, which people in Fombawi have developed over time. Similar experiences confirm the relevance of institutions that guide peaceful human–crocodile relationships (Luo et al., 2009; Jimoh et al., 2012; Mukul et al., 2012). Interestingly, such institutional solutions already exist in Fombawi, probably because the community was already living near a smaller pond with crocodiles before the dam was built. Thus, instead of assuming that appropriate institutions are lacking and need to be designed (Hounkonnou et al., 2012), it is important to capitalize on the institutional variation that already exists (Sherwood et al., 2012; Leeuwis, 2013).

As argued by Zaffron (1995) and Bohm (1996), intentionally constructed conversations in which participants engage in a sustained and collaborative investigation of assumptions and backgrounds that underlie their everyday practices and interactions can be

very useful for creating new contexts that allow for new rules and practices. It is therefore recommended that the stakeholders in the three communities should discuss their different solutions to the problem, including the traditional and practical institutions of the Fombawi people, with the aim of finding out whether these could also be effective in the contexts of Nikki and Sakabansi.

3.6 Conclusion

Although people in the three communities studied in Northern Benin are all confronted with crocodiles on a daily basis, they deal with them in different ways, including applying both formal and informal institutions that support a more or less peaceful co-existence with the crocodiles. Accessing the frames of diverse stakeholder groups has resulted in new and useful insights that elucidate the contextually of human–crocodile interactions around APDs. It appears that the behaviour of wildlife – at least to a certain extent – is constructed in interaction, both between people and crocodiles and among people. Our study has shown the relevance of ongoing daily actions and interactions in specific contexts for developing specific human–crocodile relationships. Since changing actions and institutions is shaped in changing conversations, and vice versa (Ford, 1999), the different ways people deal with crocodiles in the three communities may be a good starting point for a dialogue focused on finding ways to manage wildlife effectively in the APDs.

This conclusion forms the basis for recommending intensive communication between stakeholders from the different villages in order to exchange experiences, practices, and ideas for peacefully dealing with the crocodiles, capitalizing on existing institutional diversity as the inspiration for change.

CHAPTER 4

Challenges for smallholder vegetable producers to benefit from agro-pastoral dams in northern Benin

Kpéra[abcd], G.N., Saïdou [e], A., Sègnon[e], A.C., Mensah[d], G.A., Aarts[b], N., van der Zijpp[a], A.J.

[a] Animal Production Systems Group, Wageningen University, Wageningen, The Netherlands
[b] Communication Strategies Group, Wageningen University, Wageningen, The Netherlands
[c] Laboratoire d'Ecologie Appliquée, Faculté des Sciences Agronomiques, Université d'Abomey Calavi, Bénin
[d] Institut National des Recherches Agricoles du Bénin, Abomey Calavi, Bénin
[e] Département de Production Végétale, Faculté des Sciences Agronomiques, Université d'Abomey Calavi, Bénin

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Abstract

Vegetable produced around agro-pastoral dams during the dry season in northern Benin are the only source of fresh vegetable for local people and contribute to improved small vegetable producers' livelihoods. The study examined dry season vegetable production systems around Agro-pastoral dams and identified constraints that hinder this activity. Information was collected through group discussions, individual interviews with vegetable producers, and participant observations in the villages Nikki, Sakabansi, and Fombawi. The vegetables grown include *Amaranthus cruentus* L., *Sesamum indicum* L., *Abelmoschus esculentus* (L.) Moench), *Capsicum frutenscens* L., *Corchorus olitorus* L., *Lactuca sativa* L. and *Brassica oleracea* L. A difference exists between men and women in Nikki and Sakabansi regarding amount of land farmed and in soil fertility management in the three dams. Also a difference exists between men and women in soil fertility management practices. Constraints affecting vegetable production include access to water, seedling and mature plant destruction by livestock, pest and disease management, access to markets, access to land, access to credit, lack of equipment, seed, fertilizer and pesticides, and problems with crocodiles.

Keywords: Gender, water management, vegetable, cropping systems, constraints.

4.1 Introduction

The lack of vegetable consumption can have deleterious effects on human health and may affect the attainment of many of the Millennium Development Goals (Keatinge et al., 2011). Cultivated vegetables in Africa represent important components of diets (Shackleton et al., 2009; James et al., 2009). They provide a cheap and reliable source of minerals, proteins, vitamins, and other elements essential for human health and wellbeing, and contribute to prevention of nutritional deficiency diseases (James et al., 2009; Sabo and Zira, 2009; Sakpere et al., 2015). In Africa, vegetable production has been on rain fed production, with little emphasis on dry season production (Yusuf et al., 2015). Vegetable production is a source of income and contributes to food security in urban, peri-urban, and rural areas in West Africa (James et al., 2009; Sabo and Adeniji, 2007; Achigna-Dako et al., 2008; Ahouangninou et al., 2013; Baruwa et al., 2013). However, vegetable production is constrained by inadequate infrastructure, and agronomic and socio-economic variables which

manifest as reduced yield (Sabo and Zira, 2009). In southern Benin, vegetable production is well established in urban and peri-urban areas and managed by young people (Adorgloh-Hessou, 2006; Amadji et al., 2009). In northern Benin, this activity is observed mainly in inland valleys and around agro-pastoral dams (APDs), where it represents the main dry season activity, the main source of fresh vegetables, and a reliable source of income of the rural population. The APDs contain about meters of water. Resource-poor farmers, especially women, generally working with producer associations, pursue this livelihood strategy (Capo-Chichi et al., 2009; Kpéra et al., 2012).

The Benin government supports intensification of the agricultural sector with products such as maize, rice, vegetables, milk (from dairy production), and fish (MAEP, 2007). The government of Benin initiated several development programs to boost the agricultural sector partially through vegetable production and contribute to food security (MAEP, 2007; Gadelle, 2010). This programmes included the National Programme for Food Security (PNSA : *Programme National de Sécurité Alimentaire*), the Food Security through Agricultural Intensification Programme (PSAIA: *Programme de Sécurité Alimentaire par l'Intensification Agricole*), the Strategic Plan for the Revival of Agricultural Sector (PSRSA*: Plan Stratégique pour la Relance du Secteur Agricole*), and the Emergency Support Programme for Food Security (PUASA: *Programme d'Urgence d'Appui à la Sécurité Alimentaire*). However, vegetable production suffers from technical and institutional constraints in Benin (Singbo and Nouhoeflin, 2004; Sègnon, 2011; Kpéra et al., 2012; Ahouangninou et al., 2013). There are reduced yields, low income, pesticide contamination, insufficient and irregular vegetables supply (Tiamiyou and Sodjinou, 2003), and price speculation at particular times of the year (Capo-Chichi et al., 2009).

The APDs are used for drinking water for livestock and local communities, fish production, swimming, bathing, washing and cleaning, road and house construction and vegetable production (Kpéra et al., 2012). Diverse stakeholders use APDs for different goals and purposes, leading to conflicts. The main stakeholder groups include herders, vegetable farmers, food crop and cotton farmers, daily users, fishermen, dam management committee members, council in charge of the management of the dams and crocodiles. These conflicts may affect water quality, silting of APDs, and other APD ecosystem services (Kpéra et al., 2012). There is a need to explore options to help local communities maintain and/or increase APD ecosystem services, by optimizing vegetable production, improving vegetable producers' livelihoods, and ultimately creating conditions to optimize the use and management of APDs. This research undertook to: (i) determine characteristics of vegetable

producers around APDs, (ii) describe their cropping systems, (iii) identify constraints hindering vegetable production, and (iv) describe vegetable producer organizations at 3 APDs.

4.2 Materials and Methods

4.2.1 Research area

The agro-pastoral dams were selected on the basis of previous studies (Capo-Chichi et al., 2009; Kpéra et al., 2012) because there was intensive dry season vegetable production activities near them. The research area includes local communities living around the Nikki, Sakabansi, and Fombawi APDs in Nikki District, Borgou Department, which has 20 APDs, in north-eastern Benin. The area lies between 9°56'2"N and 3°12'16"E. The agro-pastoral dams were constructed by the national government as watering holes for livestock and for agricultural sector development.

These APDs were selected because they represent the dams located in Nikki District and because they vary in terms of market access, vegetable production plot size, and number of vegetable producers engaged in this activity. The features of the APDs (Kpéra et al., 2012) are:

(i) Located within the boundary of Nikki town with 31,661 inhabitants; Nikki agro-pastoral dam was constructed in 1972 and renovated in 1996. It has a capacity of 257,000 m^3 and a watershed area of 120 km^2 (Capo-Chichi et al., 2009). The Nikki APD is 1 km from the village. The vegetable plots are located upstream from the dam. There are 2 vegetable producer associations in Nikki: one "*Ansouroukoua*" with 20 original members, now consisting of 150 members (130 women and 20 men), and another "*Donmarou*" consisting of 50 members (40 women and 10 men) having access to markets in Nikki town and in Chikandou, Nigeria, 22 km away.

(ii) Constructed in 1985 and covering 1 ha, the Sakabansi agro-pastoral dam has a capacity of 200,000 m^3 surrounded by a watershed of 20 km^2 (Capo-Chichi et al., 2009). The dam is 3 km from the village of Sakabansi, which has a local market. The Sakabansi vegetable producer association "*Ankua mon*" was created in 1998 and now has 30 members (29 women and 1 man). The association was restructured in 2004 helping members to obtain

seed and providing training in cropping techniques. The vegetable production plots are located upstream from the Sakabansi dam.

(iii) Constructed in 1989, the Fombawi agro-pastoral dam has a capacity of 17,000 m^3 and a watershed of 2.4 km^2 (Capo-Chichi et al., 2009), is 500 m from the village of Fombawi which has a local market (Kpéra et al., 2012), has 32 women members in a co-operative "*Angara debu*", with vegetable plots located downstream of the dam close to the village. Because of perennial destruction of the plots by local livestock, women vegetable producers in Fombawi decided not to crop during the dry season 2010–2011.

4.2.2 Data collection and analysis

The research, conducted during the dry season 2010–2011, was carried out in 2 phases: an exploratory survey and an in-depth survey. The introduction of the researcher into each community was facilitated by the local extension service and the dam management teams. The exploratory survey aimed to obtain an overview of vegetable production systems operating in the watershed of each dam and to identify stakeholders and key informants. This phase allowed better formulation of research objectives and an improvement of initial questionnaire. Group discussions with representatives of the vegetable producer associations and participant input regarding plot size, vegetables grown, and pest, and soil management strategies were used to collect information. Proportional sampling of respondents resulted in 37 (19 males and 18 females) of 200 in Nikki; 15 females of 32 in Fombawi (men are not involved in vegetable production there), and 18 (17 females and the only 1 male) of 30 in Sakabansi, a total of 70 respondents belonging to the vegetable producer associations. Individuals, especially association leaders, were visited many times to obtain follow up information. The farm plot size of 55 producers was measured in Nikki and Sakabansi and fertilizers and pesticides used by vegetable producers recorded in the 3 villages. Open-ended questionnaires were used during this phase. The main subjects of questionnaires included socio-economic characteristics of respondents, cropping systems with emphasis on vegetables, soil fertility management, pest and disease management, constraints that the 70 vegetable producers always faced, and organization of the associations of vegetable producers at the 3 agro-pastoral dams and how vegetable production could affect APD ecosystem services. Vegetable producers were asked to prioritize by ranking and weighting constraints on a 10-point scale; very great importance = 1 little importance = 10.

Data were analysed using the statistical software MINITAB 16 (Ryan et al., 2012) Descriptive statistics (percentages, means, and frequency) were used, and differences between distributions of responses determined by the χ^2-test. Kendall's test using IBM SPSS Statistics 21 (Field, 2013) was used to rank the constraints hindering vegetable production.

4.3 Results

4.3.1 Characteristics of the vegetable producers based on plot size and gender

Vegetable production around the APDs is conditioned by the factor of land. Income of producers depends on size of the land cultivated. Vegetable producers can be categorized into groups depending on plot sizes: large vegetable producers (those who own more than 1,000 m^2), medium vegetable producers (those who own between 500 m^2 and 1,000 m^2), and small vegetable producers (those who own less than 500 m^2). Whatever the plot size, they all use family member labor. In addition, the large vegetable producers in Nikki hire farm labor. The vegetable producers plot size and gender in Nikki and Sakabansi varied (Table 4.1).

Table 4.1 Typology by plot size and gender of vegetable producers around agro-pastoral dams in villages of Nikki and Sakabansi.

	Nikki		Sakabansi	
	Number and (%)[a]		Number and (%)[a]	
Plot size (m^2)	F	M	F	M
< 500	14 (37.8)	9 (24.3)	17 (94.4)	0 (0)
[500–1,000]	5 (13.5)	5 (13.5)	0 (0)	1 (5.6)
> 1,000	0 (0)	4 (10.8)	0 (0)	0 (0)
Total	19 (51.3)	18 (48.6)	17 (94.4)	1 (5.6)

[a] percent of all vegetable producers in each location, male (M) and female (F); level of significance determined by Chi-square test: Male vs Female = 12.092**; p=0.002

Fewer women have small plots in Nikki than in Sakabansi. In contrast, only men in Nikki cultivate large plots which represent a minority; some also own small and medium-size plots. In Sakabansi, the only male producer owns a medium-size plot. There was a significant gender difference in plot size in Nikki and Sakabansi.

4.3.2 Vegetable species and cropping systems

A variety of vegetables are grown around the vicinity of the APDs (Table 4.2). Producers in Nikki tailored their selection of vegetable species to the demand in the Nikki town market and in the Chikandou market (in Nigeria). Vegetable species cultivated by Nikki, Sakabansi, and Fombawi producers are almost the same every year. These include lettuce (*Lactuca sativa* L.), cabbage (*Brassica oleracea* L.), amaranths (*Amaranthus cruentus* L.), sesame (*Sesamum indicum* L.), okra (*Abelmoschus esculentus* (L.) Moench), hot pepper (*Capsicum frutenscens* L.), tossou jute (*Corchorus olitorus* L.), tomato (*Solanum lycopersicum* (L.) H. Karst.), roselle (*Hibiscus sabdariffa* L.), and African eggplant (*Solanum macrocarpon* L.).

In Fombawi and Sakabansi, amaranth, sesame, and okra are cultivated by most female vegetable producers; roselle, cabbage, and African eggplant are less, or not at all, cultivated. In Nikki, vegetable producers cultivate a larger variety of vegetable species than producers in Sakabansi and Fombawi. Tomatoes are cultivated by men in Nikki and Sakabansi only. In Nikki, roselle and African eggplant are grown exclusively by women.

Vegetables grown by producers around the Nikki agro-pastoral dam varied by plot size and gender (Table 4.3). On large plots, men grow hot peppers, lettuce, tomatoes, and cabbage to supply the Chikandou market. Most growers produce their own seed. A few in Nikki buy improved seed of lettuce, cabbage, and tomato from Parakou and Nigeria, although they are not always available.

Table 4.2 Vegetables grown by producers around Nikki, Fombawi, and Sakabansi agro-pastoral dams by gender (%); F = females, M = males.

Vegetable species	Nikki (n=37) Frequency (%)		Fombawi (n=15) Frequency (%)		Sakabansi (n=18) Frequency (%)	
	F (n=18)	M (n=19)	F (n=15)	M (n=0)	F (n=17)	M (n=1)
Amaranthus cruentus (Amaranths or African spinach)	100	63.2	100	0	100	100
Sesamum indicum (Sesame plant)	83.3	5.3	100	0	100	100
Abelmoschus esculentus (Okra)	66.7	31.7	100	0	76.5	100
Capsicum frutenscens (Hot pepper)	27.8	100	20.0	0	58.8	100
Corchorus olitorius (Tossa jute)	44.4	21.1	33.3	0	47.1	0
Lactuca sativa (Lettuce)	33.3	31.6	20.0	0	29.4	100
Lycopersicon esculentum (Tomato)	22.2	47.4	46.7	0	0	100
Hibiscus sabdariffa (Roselle)	83.3	0	13.3	0	5.9	0
Solanum macrocarpon (African eggplant)	77.8	0	0	0	0	0
Brassica oleracea (Cabbage)	22.2	42.1	0	0	0	0

Table 4.3 Vegetables grown in vicinity of the Nikki agro-pastoral dam by plot size and gender.

Vegetable species	Plot size (m^2)	Number by gender in Nikki Female	Male
Amaranthus cruentus	< 500	14	7
(Amaranths or African	[500–1,000]	4	4
spinach)	> 1,000	0	1
Sesamum indicum	< 500	12	1
(sesame plant)	[500–1,000]	3	0
	> 1,000	0	0
Abelmoschus esculentus	< 500	9	3
(Okra)	[500–1,000]	3	3
	> 1,000	0	0
Capsicum frutenscens	< 500	1	9
(Hot pepper)	[500–1,000]	4	5
	> 1,000	0	4
Corchorus olitorius	< 500	7	1
(Jute mallowjute)	[500–1,000]	1	3
	> 1,000	0	0
Lactuca sativa	< 500	2	0
(Lettuce)	[500–1,000]	4	3
	> 1,000	0	3
Lycopersicon esculentum	< 500	0	0
(Tomato)	[500–1,000]	3	5
	> 1,000	0	4
Hibiscus sabdariffa	< 500	10	0
(Roselle)	[500–1,000]	5	0
	> 1,000	0	0
Solanum macrocarpon	< 500	9	0
(African eggplant)	[500–1,000]	5	0
	> 1,000	0	0
Brassica oleracea	< 500	0	0
(Cabbage)	[500–1,000]	4	4
	> 1,000	0	4

The cropping systems of vegetable producers at the Nikki agro-pastoral dams vary by gender and plot size (Figure 4.1). About half of women owners of small plots use monocropping; fewer use intercropping and crop rotation. Women owners of medium plots adopt crop rotation and intercropping systems at equal levels and monocropping was adopted by the majority. Whatever plot size men almost always opt for crop rotation. In Sakabansi, monocropping, intercropping systems, and rotation in order of preference were adopted by vegetable producers, and the only man who owns a medium size plot uses intercropping.

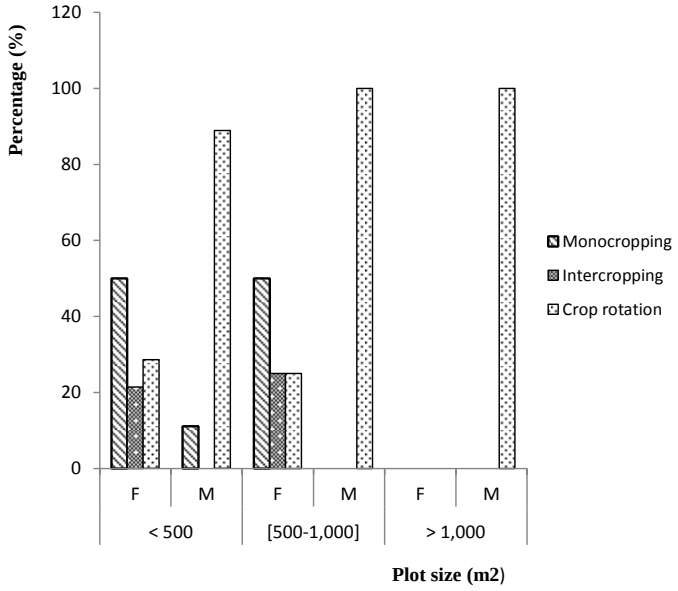

Figure 4.1. Cropping systems of vegetable producers around the Nikki agro-pastoral dams by gender and plot size

In all APDs, a majority of growers apply organic fertilizer, including cattle manure, household waste, and – on a small scale – poultry manure (Figure 4.2). Mineral fertilizer is applied mainly by men on medium and large plots in Nikki. Combined organic and mineral fertilizer use is limited to small plots. Inorganic fertilizer, used because specific fertilizers for vegetables, is unavailable at the communal centre for agriculture promotion (CeCPA: Centre Communal de Promotion Agricole), is mainly cotton-formulation fertilizer NPK-SB (14N-23P-14K-6S-1B) and urea.

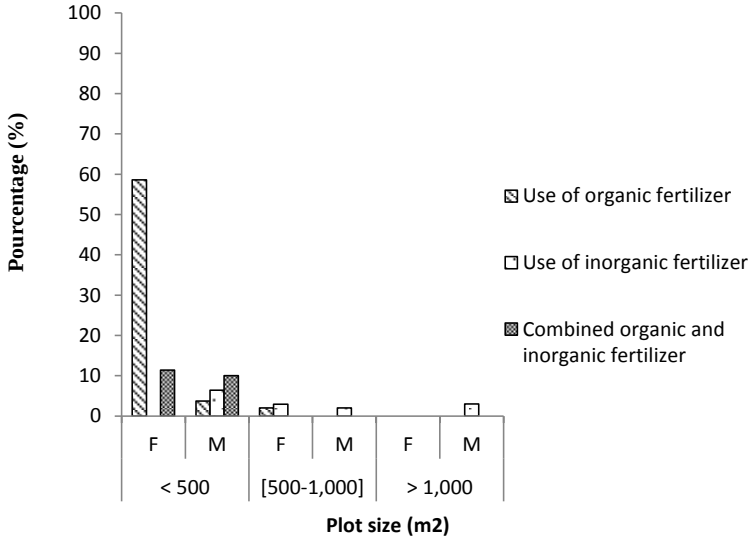

Figure 4.2 Soil fertility management of vegetable producers at the Nikki agro-pastoral dam by sex and plot size ; F=Female; M=Male

Men have 3 sources of synthetic fertilizer: CeCPA, Chikandou market, and local markets. The difference resides in that CeCPA provides fertilizers and on credit while they are available for cash and for less cost in Chikandou market and local markets. There was a significant difference between men and women in soil fertility management practices in Nikki.

Vegetable producers have developed strategies to control pests and diseases in the study areas (Table 4.4). In general, cotton pesticides, bio-pesticides, especially neem (*Azadirachta indica* A. Juss) leaves and seed extract harvested from trees in the villages, and prophylactic practices are applied by both men and women vegetable producers (Table 4.4).

Table 4.4 Pest and disease management practices by male or female producers around agro-pastoral dams by gender in Nikki, Fombawi, and Sakabansi.

Pest and disease management practices	Male		Female	
	Frequency	(%)	Frequency	(%)
Use of pesticide	11	15.7	3	4.3
Use of neem leaves and seed	8	11.4	17	24.3
Spreading wood ash	0	0	14	20.0
Prophylactic practices	1	1.4	16	22.9
Total	20	28.5	50	71.5

Level of significance determined by Chi-square test.
Male vs. Female = 24.602^{***}; p=0.000

Only women apply wood ash. Similar to fertilizer use, the pesticides used are mainly those recommended for cotton (not recommended for vegetables) because of non-availability of specific pesticides for vegetables (Table 4.5). Overall, minorities of vegetable producers use bio-pesticides and prophylactic practices to control pests. A small percent of vegetable producers use pesticides. The gender difference regarding pest and disease management practices was significant in Nikki. Small plot owners are more likely to use prophylactic methods, spread wood ash, and use neem leaves and seed (Table 4.6). Male owners of medium and large plots use pesticides mainly in Nikki. The plot size difference was significant for pest and disease management practices in Nikki and Sakabansi.

Table 4.5 Pesticides labelled for cotton used by vegetable producers in Nikki.

Pesticides	Active ingredients
Tihan 175 O-Teq	*(Flubendiamid 100–Spirotetramate 75 g·L^{-1})*
Cotofan 350 CE	*Endosulfan*
Nurelle D 236 EC	*Cypermethrin-Chlorpyriphos ethyl*
Cotalm P 218 CE	*Lambdacyhalothrin-Crofenofos*
Lambdacal P 215 EC	*Lambdacyhalothrin-Profenofos*
Capt 88 CE	*Cypermethrin-Acetamipride*
Thunder 145 0-Teq	*Betacyfluthrin-Imidacloprid*

Table 4.6 Pest and disease management practices of vegetable producers around the agro-pastoral dams by plot size in Nikki and Sakabansi.

	Plot size (m²)					
Pest and disease management	<500		[500-1,000]		>1,000	
practices	Frequency	(%)	Frequency	(%)	Frequency	(%)
Use of pesticide	5	9.1	6	10.9	3	5.5
Use of neem leaves and seeds	14	18.6	3	5.5	1	1.8
Spreading wood ash	11	20	0	0	0	0
Prophylactic methods	10	25.7	2	3.6	0	0
Total	40	72.7	11	20	4	7.3

Level of significance determined by Chi-square test: Plot size = 14.566***

4.3.3 Marketing of vegetables

In Nikki District, marketing of dry season vegetables has never been an issue for producers because of the high demand of fresh farm products during the dry season. However, with the availability of ADPs direct and indirect marketing are used. In Nikki, Sakabansi and Fombawi, vegetable producers rely on local markets to sell their products directly to local consumers. As alternative peddling vegetables to local families occurs, direct sale at the farm gate occurs. This marketing is mostly done by owners of small and medium size plots and embraces all types of vegetables except lettuce and cabbage. Producers from Sakabansi and Fombawi depend exclusively on direct marketing to sell their vegetables.

In Nikki male vegetable producers, with large plots, rely on the Chikandou market (Nigeria) to sell their hot peppers, lettuce, tomatoes, and cabbage. Intermediaries from Chikandou come to Nikki to buy vegetables at the farm gate. These vegetables are resold to the Chikandou market at higher prices. This is possible since few producers prefer to harvest their vegetables and transport them to Chikandou market to get better prices.

4.3.4 Constraints facing vegetable producers

In Nikki District including access to water, vegetable destruction by livestock, pest and disease management, access to markets, access to land, access to credit, lack of equipment, lack of seed, fertilizers, and pesticides, problems with crocodiles, and theft affect production. The importance of these constraints varies from one agro-pastoral dam to another (Table 4.7).

In all agro-pastoral dams, destruction of vegetables by livestock is a main constraint, followed by lack of equipment, access to water, and pests and diseases. In Nikki, vegetable producers complained more about access to water, pests and diseases, lack of equipment, and destruction of seedlings and vegetables by livestock. In Sakabansi the major constraints were lack of equipment, destruction of seedlings and vegetables livestock, lack of seed, fertilizers, and pesticides, and problems with crocodiles. In Fombawi, lack of equipment, destruction of seedlings and vegetables by livestock, lack of seed, fertilizers, and pesticides, and pests and diseases were the main constraints hindering production. The destruction of vegetable plots by livestock has stopped vegetable production in Fombawi. Gender did not affect ranking of constraints, and plot size resulted in the same priorities as above.

Table 7. Ranking of vegetable producer constraints in Nikki, Sakabansi, and Fombawi.

	Nikki		Sakabansi		Fombawi		Overall	
Constraint	Mean Rank	Ranking	Mean Rank	Ranking	Mean Rank	Ranking	Mean Rank	Overall[a] Ranking
Access to water	1.78	1	6.06	6	6.70	6	3.94	3
Vegetable and seedling destruction by livestock	3.28	4	1.67	2	1.00	1	2.38	1
Pests and diseases	3.16	2	5.94	5	4.17	4	4.09	4
Access to market	9.50	10	9.39	8	9.27	9	9.42	10
Access to land	8.81	9	9.56	9	7.30	8	8.68	9
Access to credit	5.69	6	6.94	10	3.20	3	5.48	6
Lack of equipment	3.22	3	1.33	1	2.33	2	2.54	2
Lack of seed, fertilizer, and pesticides	5.59	5	3.78	3	5.07	5	5.01	5
Problems with crocodiles	8.01	8	3.78	3	9.23	10	7.19	8
Vegetables stolen	5.95	7	6.56	7	6.73	7	6.27	7
	p=0.000 (n=37)		p=0.000 (n=18)		p=0.000 (n=15)		p=0.000 (N=70)	

[a] Kendall's Test; Overall = Nikki-Sakabansi-Fombawi.

4.3.5 Vegetable producer organizations

Vegetable producers at the ADPs are organized in associations, but work individually on their plots. The motivation underlying creation of associations was access to credit with local banks like CLCAM (CLCAM: Caisse Locale de Crédit Agricole Mutuel) and NGO SIA N'SON and technical assistance from the CeCPA extension service and development projects (PADPPA: Programme d'Appui au Développement Participatif de la Pêche), PDRT: Projet de Développement des Racines et Tubercules) are conditional on membership in an association. Individuals not in associations cannot obtain credit from NGOs, or banks, which provide security in case of failure to repay their debt.

Each association is headed by a working with the president being an elder, and the secretary and the treasurer selected from among those with educations. To become a member of an association, the applicant must contact the working committee who informs the association. The working committee determines whether the applicant is of good character and able to work in a team. Once the applicant is approved, he/she is allowed to pay the membership fee: 1,000 F CFA (€1.52) (Donmarou) and 1,200 F CFA (€1.82) (Ansouroukoua) in Nikki, 500 F CFA (€0.76) in Sakabansi and Fombawi. The working committee is responsible for allocation of land to the new member who decides how much land is to be allocated to which vegetables. In Nikki, members pay an annual membership fee to both associations. The money collected is used to buy soya beans when the price is low; these beans are sold when they become expensive in the market. The profit is used to assist members facing monetary problems. In Sakabansi and Fombawi, members do not pay an annual membership fee but communally work plot and sell the produce.

According to the Nikki vegetable producers, at a meeting in February 2010, the Nikki vegetable producers and farmers were accused of contributing to silting of the dam and to water pollution through their activities. The council and the CeCPA advised them to not farm within a 1,000 m radius of the dam. Attempts made by the Nikki dam management committee and Nikki council to relocate vegetable farmers from upstream to downstream sites which were not successful due to no infrastructure downstream; inappropriate ground and inaccessible water. The council is seen by vegetable producers as an enemy. Although the CeCPA is aware of the issue, the relocation of 200 vegetable producers and several farmers to downstream sites still remain a process of dialogue and common agreement between producers, Nikki council and CeCPA.

In Sakabansi, vegetable plots are located upstream. Pollution is less serious because bio-pesticides are mainly used. In Fombawi, vegetable plots are located downstream and do not have any negative effect on the dam.

4.4 Discussion

4.4.1 Gender-related characteristics of producers, crops and cropping systems

The gender difference in vegetable production in the villages can be explained by the intervention of previous development projects – ended in 2008 – that included only women in dry season vegetable production around APDs. In Sakabansi and Fombawi villages the only man cultivating vegetables in Sakabansi is the dam security guard. In Nikki, which is considered a peri-urban zone, men were involved in this activity because Nikki is better connected with roads to Nigeria and more land is available for agriculture. Oluoch et al. (2009) observed that, in most rural areas, vegetable production and marketing is undertaken mainly by women. van Rensburg et al. (2007) reported that, as soon as a crop becomes a significant source of income, men become more involved, as is the case with many other natural resources. This may be one of the reasons why more men are involved in vegetable production in urban and peri-urban areas, and why marketing is left to women in Benin. In Sakabansi and Fombawi, men are not interested in vegetable production because of absence of potential markets and the low revenue. Togbé et al. (2012) stated that cotton, the main cash crop in Northern Benin, is cropped by men, because of the income it generates compared to other crops. The plot size difference between men and women owners can be explained by working conditions, which are unfavourable for women. Women have less access to labour for hard work such as ploughing, watering, and weeding because of low incomes. They also spend time on care for the family. In Nikki, the men's cropping system consists of large plots, more exotic and marketed vegetables (lettuce, tomatoes, and cabbage), more intensive use of mineral fertilizers and pesticides, and crop rotation. Their cropping system is less traditional and more dependent on external inputs. In contrast, women cultivate traditional vegetables and use organic fertilizer (animal manure) and bio-pesticides (neem and wood ash). This can be explained by men having access to the Chikandou market (Nigeria) to purchase inputs and sell vegetables. Men and women can learn from each other in order to maximize sustainable vegetable production that is by applying organic fertilizers, biopesticides and crop rotation.

4.4.2 Constraints relating to vegetable production

In Nikki, Sakabansi, and Fombawi APDs, the destruction of vegetables and seedlings by livestock was indicated as a constraint to vegetable production. A possible solution to destruction of seedlings and vegetables by livestock is to fence plots using tree trunks easily available in the area rather than expensive barbed wire. Corridors for livestock to have access to dams should be kept opened through the year.

Abang et al. (2014) stated that pests and diseases represent the main challenge for vegetable production. Neem products could be an environmentally friendly solution for vegetable producers against pests and diseases, conditional on local production and trade of neem products. Neem products have other beneficial effects, such as the treatment of human diseases, including malaria (Koul and Wahab, 2004). Unfortunately, the price of neem products is high in West Africa (Amoah et al., 2006) and limits its accessibility. However, neem products could be attractive products for associations: for their own use as biopesticides and to sell in local markets. Because of non-availability of vegetable pesticides in Nikki, male producers resort to easily available and effective cotton pesticides. This practice poses a risk for the APD ecosystem services (water quality, soil, and biodiversity) (Pimentel et al., 1993) and food safety of the vegetables (Ahouangninou et al., 2013).

Agbaeze and Onwuka (2014) indicated that permanent access to microcredit contributes to alleviation of rural household poverty and improves small farmer's ability to participate in, and benefit from, development opportunities. The high interest rate charged by local banks is a limiting factor for vegetable producers in West Africa (Adebisi-Adelani et al., 2011). At Nikki District associations could use profit from the soya bean trading to provide small credits to members who need equipment while ensuring that the association can carry the risk if a member defaults on repayment of the credit. Another solution is to organize access to microcredit through food crop and cotton farmer-based organizations to assist in provision of neem oil, or other, environmentally friendly pesticides. The producers can reimburse the cost of the inputs from sale proceeds of their produce.

4.4.3 Vegetable producer organizations and sustainability of vegetable production around agro-pastoral dams

Vegetable producers from the three APDs value the association for financial security in times of need and exchange of labour. The Nikki associations engage in soya-bean trading to

support members in need, but the Sakabansi and Fombawi associations do not offer any kind of such support. In the three villages, they exchange labour for more profit. They have, however, little concern about access to inputs, communication tools, market strategies, the sustainability of the activity, and the sustainability of the APDs.

The general problem of many APDs in Nikki District is the upstream position of the vegetable plots causing conflicts with Nikki council. Serious issues are the silting of the dam and water pollution. Relocation of producers to downstream sites should be a sustainable solution. As the APDs are public goods and Nikki council wants to move associations to downstream locations, the council should first start with respecting the formal rules and their own informal rules related to the management of APDs (Kpéra et al., 2011; Kpéra et al., 2014) and second accept responsibility for assisting deforestation of the new sites, opening access roads to the sites, and contributing to the purchase of irrigation equipment. Furthermore, the availability of bio-pesticides and fertilizers can be negotiated by Nikki District at Borgou Department level.

In Kalalé District, located 44 km north of Nikki, vegetable producers are well organized, farm upstream, enjoy access to inputs and high quality vegetable markets, and are supported by Kalalé council. An exchange visit to Kalalé District could be organized for discussions between vegetable producers and council members. This visit could be beneficial for the council and the producer associations and contribute to sustainable vegetable production around APDs in Nikki District.

4.5 Conclusion

Vegetable production around the agro-pastoral dams in Nikki District is the main source of vegetables for the local population in the dry season. The majority of the vegetable producers are women who are involved part-time. Unlike women, men in Nikki grow exotic vegetables and marketable vegetables on larger plots, use mineral fertilizer and cotton pesticides, and practice crop rotation. Indigenous leafy vegetables – especially amaranth, sesame plant, and okra – are cultivated by women and men at all dams. Major constraints to vegetable production include access to water, vegetable and seedling destruction by livestock, pests, and diseases. Moreover, Nikki council has accused the Nikki and Sakabansi producers of silting and water pollution of the APD caused by their upstream plots, and this has led to conflicts. In all, to ensure sustainable production of dry season vegetables in Nikki District, solutions have

to be found for:

- The destruction of vegetables by livestock;
- The sustainability of vegetable production around the agro-pastoral dams based on bio-pesticide application and manure;
- The impact of vegetable production on the silting and the water quality of the agro-pastoral dams;

These solutions should be realized by:

- Strengthening farmers' capacity to engage in the best cultural practices for maintaining and /or improving the APD ecosystem services;
- Creating a more active role for the producer associations to support their members with sustainable modes of vegetable production;
- Organizing a visit to Kalalé District in which producer association members and the Nikki council can discuss sustainable management of vegetable production and district governance of the APDs;
- Exchanging, training and building the capacity of all players in the vegetable value chain in order to ensure sustainable production, and contribute to poverty alleviation and food security.

CHAPTER 5

Water quality and fish diversity as indicators of the health status of the agro-pastoral dam ecosystem in Benin: a preliminary study

Kpéra G.N.[abcd], Ahouansou Montcho S[e]., Mensah G.A.[d], Aarts N.[bf], van der Zijpp A.J.[a]

[a] Animal Production Systems Group, Wageningen University, The Netherlands

[b] Strategic Communication Group, Wageningen University, The Netherlands

[c] Laboratoire d'Ecologie Appliquée, Faculté des Sciences Agronomiques, Université d'Abomey Calavi, Bénin

[d] Institut National des Recherches Agricoles du Bénin, Abomey Calavi, Bénin

[e] Laboratoire d'Hydrobiologie et d'Aquaculture, Faculté des Sciences Agronomiques, Université d'Abomey-Calavi, Bénin

[f] Amsterdam School for Communication Research, University of Amsterdam, Amsterdam, The Netherlands

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Abstract

Ecosystem services – the benefits that people obtain from ecosystems – are a lens through which we can understand human relationships with the environment. Based on a study in three agro-pastoral dams (APDs) in Nikki, Sakabansi, and Fombawi in Nikki District in northern Benin, this chapter aims to: characterize APD water quality (physical, chemical, and microbiological composition), identify the diversity of fish, and estimate fish biomasses in the APDs. The ecosystem services framework underlies this chapter. APD water quality is problematic because of the significantly high levels of nitrite, nitrate, iron, and chemical oxygen demand. Nitrate and nitrite, probably the result of agricultural runoff, dump runoff, and human and animal wastes, may be responsible for the invasion of aquatic plants in the APDs resulting from eutrophication reducing water quality and altering the ecological structure and function of APDs. The water in APDs is unsuitable for both human and livestock consumption because it is contaminated with harmful bacteria (Coliforms, *Enterococcus faecalis*, *Escherichia coli*, spore of *Clostridium*, *Salmonella typhi*, *Campylobacter jejuni*, and so forth). The total fish catch in numbers is highest in Fombawi (43%), followed by Sakabansi (29%) and Nikki (28%). Four large size marketable species are targeted for fishing: *Clarias anguillaris*, *Clarias gariepinus*, *Oreochromis niloticus*, and *Tilapia mariae*, representing, respectively, 31%, 44%, and 86% of the total fish population in Nikki, Sakabansi, and Fombawi. *O. niloticus* is the only prominent large species and is not part of the natural population. The almost complete absence of *T. mariae* and *C. gariepinus* in the Nikki APD is imputed to daily fishing. Twenty fish species were identified in the three APDs. This low diversity may be attributed to damage caused by agricultural practices, selective fishing (large size fish), and crocodile predation on fish. The study concludes that one solution for maintaining APD ecosystem health consists of watershed management based on monitoring ecosystem services such as water quality and fish biodiversity.

Key Words: Ecosystem services, pollution, biodiversity, fish species, crocodile, sustainable water resources management

5.1 Introduction

Human welfare depends directly or indirectly on the services provided by ecosystems (van Oudenhoven et al., 2012). Ecosystem services (ES) are the benefits that people obtain from ecosystems (MA, 2005). 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, nutrients, salts, and sediments present in the water and is an important attribute of hydrological services (Bonell and Bruijnzeel, 2005; 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; de Fraiture et al., 2014). Thus, in Benin, 250 agro-pastoral dams (APDs) were constructed, and they have developed into multi-purpose 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). The presence of fish and the permanence of water attract crocodiles to the APDs, sometimes obstructing human and livestock access to the dam ecosystem services (Kpéra et al., 2014). As APDs are public goods (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).

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 (Paugy et al., 2003; Jeppesen et al., 2015). Fish depletion may be caused by water pollution and oxygen reduction (Yehouenou Pazou et al., 2014). Pesticides used in agriculture can accumulate in fish (Yehouenou Pazou et al., 2014; Agbohessi et al., 2015) and affect human and crocodile health (Rauschenberger et al., 2004; Ashton, 2010) and other aquatic life (Köhler and Triebskorn, 2013).

Besides water quality, biodiversity – including the composition of genotypes, populations, species, abundance, number, functional types, communities, and landscape units – strongly influences the provision of ecosystem services and therefore human wellbeing (Díaz et al., 2005; Balvanera et al., 2006). Thus, biodiversity is important for the future sustainability of aquatic resources, including commercial fisheries (Hilborn et al., 2003). Fish communities are highly sensitive to human disturbances (fishing and pollutants) and to natural disturbances (drought, flood, and environmental degradation) (Harrison and Whitfield, 2004; Brooks et al., 2011). Hence, water quality and fish diversity have been selected in this study as indicators of APD ecosystem health.

Through the lens of three agro-pastoral dams (Nikki, Sakabansi, and Fombawi) in Nikki District, northern Benin, we address two concerns: (i) characterization of APD water quality (physical, chemical, and microbiological composition) and (ii) identification of the diversity of APD fish and fish biomass.

5.2 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 (MA, 2005; Bastian et al., 2013; Sandifer et al., 2015). The framework is presented in Figure 5.1. We first address APD ecosystems and their boundaries, with specific reference to Nikki, Sakabansi, and Fombawi. We then address the human utilization of the services and the social systems interacting with APD ecosystems, and the associated processes affecting the functioning of such ecosystems.

5.2.1 Agro-pastoral dam ecosystems and boundaries

The Nikki, Sakabansi, and Fombawi APDs are fed, respectively, by the temporary rivers Samana, Sora, and Kouena, 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 (MA, 2005).

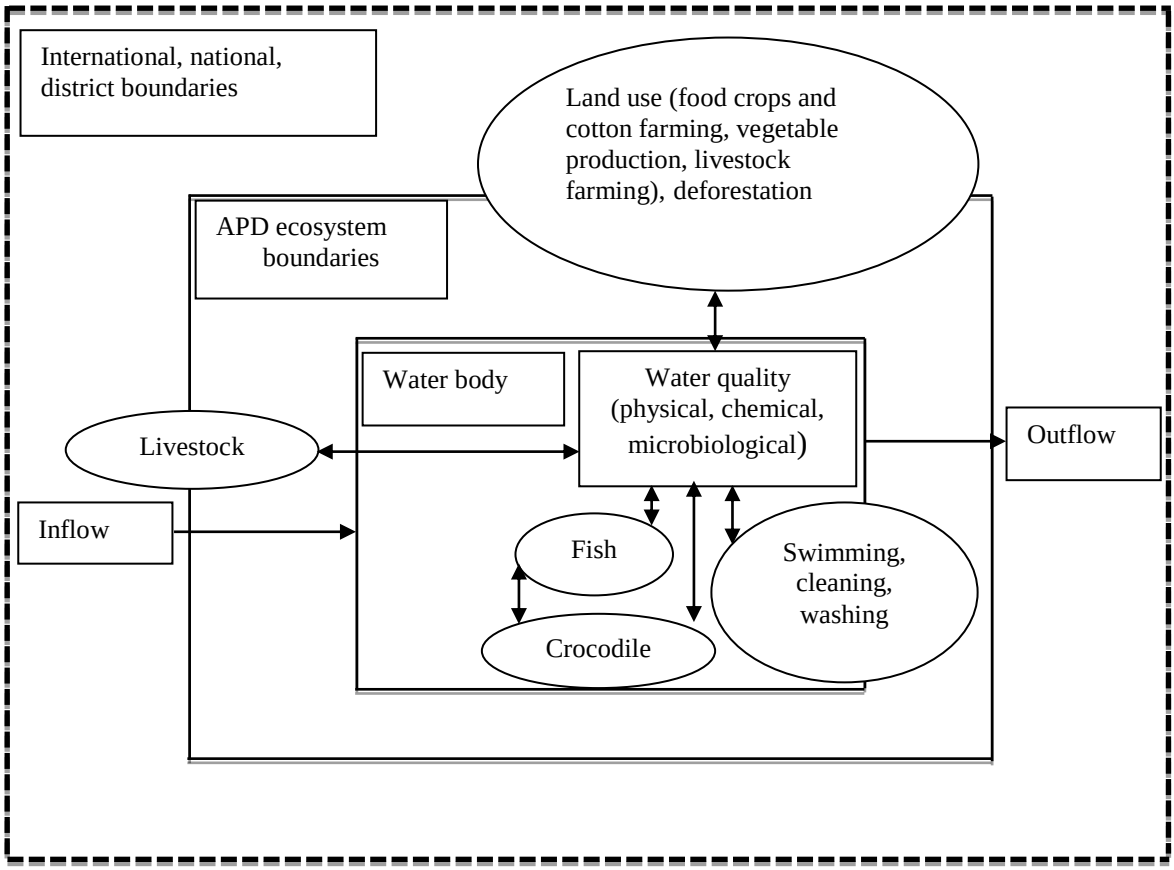

Figure 5.1 Ecosystem services and human use of the APD ecosystem

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 (respectively, 120 km^2, 20 km^2, and 2.4 km^2) (Capo-Chichi et al., 2009). As boundaries of the APD ecosystems, we considered the area located within a10 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.

5.2.2 Ecosystem services provided by APD ecosystems

ES are manifold and tightly interlinked. They can be divided (MA, 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; and (iv) cultural services that provide recreational, aesthetic, and spiritual benefits (Brauman et al., 2007; 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. Likewise, the loss of a top predator is likely to have effects (loss of resilience and a change in the ecosystem equilibrium state) on its prey and other species throughout the food web (Díaz et al., 2005).
- 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).

5.2.3 Human use of ES in APDs

We present the ES provided by the APDs (Kpéra et al., 2012) and the processes by which they may affect dam water quality and fish diversity and biomass.

- Livestock farming: Local and transhumant livestock herds consist of cattle, goats, and sheep brought by farmers to water in the dam water bodies and graze in the watershed of the APDs yearlong. Livestock deposit faeces likely to cause water pollution and contamination by bacteria infectious to both people and livestock that make use of the dams as a source of drinking water (Pimentel et al., 2004; WHO, 2011).

- Vegetable production, food cropping, and cotton farming: Vegetable production is carried out during the dry season (December to May) upstream (Nikki and Sakabansi) and downstream (Fombawi), whereas food cropping (maize, groundnut, soya bean, millet, sorghum, and yam) and cotton farming take place in the rainy season (May to October) in the vicinity of the APDs, but mainly upstream because of fertile soils. In vegetable production, organic fertilizer (manure), mineral fertilizers (NPK), and cotton pesticides

(Kpéra et al., 2012) are applied, similarly in food cropping and cotton farming. All these cropping systems may contribute to eutrophication through nitrogen contained in mineral and organic runoff from the surrounding lands (Pimentel et al., 2004; Conley et al., 2009) and through phosphate, ammonia, and nitrous oxide from fertilizers and manure. As a consequence of eutrophication, floating grasses (*Eichhornia crassipes, Nymphaea lotus, Ceratophyllum demersum*) and partially floating long-stemmed grasses (*Echinochloa pyramidalis, Andropogon gayanus*) invade APDs and are likely to have harmful effects by reducing water storage capacity in reservoirs, impeding flow, depleting fish production (Lancar and Krake, 2002; Ray and Hill, 2013), and also possibly being a health hazard by providing an ideal breeding habitat for mosquito larvae and the snail vector of bilharzia (Lancar and Krake, 2002).

- Fishing: Fish present in the APDs constitute a source of protein for the local communities in Nikki and an income-generating source for Nikki Council and fishermen (Kpéra et al., 2012). This activity was supported in 2005 by the Participative Artisanal Fisheries Development Programme (PADPPA: *Programme d'Appui au Développement Participatif de la Pêche Artisanale*). Only Nikki dam was stocked with 5,000 fingerlings of Nile tilapia (*Oreochromis niloticus*) (PADPPA, 2005). In 2009, Nikki Council collected some fingerlings of *O. niloticus* from Nikki dam and introduced them into the dams in Sakabansi and Fombawi in order to improve fishing yield in these two APDs. Fishermen targeted crocodiles for being responsible for the depletion of fish yield in APDs (Kpéra et al., 2012; Kpéra et al., 2014). The presence of crocodiles has a beneficial effect through their droppings that contain important nutrients for fish (van der Ploeg et al., 2011a).

- Other activities: other dam uses (washing, cleaning, swimming) and runoff may affect the dam ecosystem. Runoff with minerals and pathogens from wastes in Nikki town and Sakabansi and Fombawi villages ends up in the APDs. As local people defecate in the APD watershed, this can lead to water contamination by pathogens through runoff.

5.2.4 Management of agro-pastoral dams

Nikki Council represents the local government, following the decentralization reforms that started in 2005. Because of the decentralization process, the 20 APDs in Nikki District that

were formerly under the control of the local representative of the Ministry of Agriculture, Livestock and Fisheries are now under the control of the council (Kpéra et al., 2012). It is the council's duty to obtain more financial resources for local development, and APDs have been targeted as one source. The income from fish production for the 20 dams was estimated to be €1,527 in 2010 and €2,290 in 2011 (Kpéra et al., 2012). In return, the council is legally responsible for maintaining APDs by protecting their ecosystems, monitoring all the activities carried out around the dams, and mediating conflicts. However, the council has been accused by the dam users of prejudiced mismanagement of the dam income, causing a feeling of frustration among all the stakeholders (Kpéra et al., 2012).

5.3 Materials and methods

5.3.1 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. Nikki District covers an area of 3,171 km^2 and is home to 20 agro-pastoral dams. 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. This area is characterized by two types of wind chronologically established in time with variable speeds: maritime wind and dry wind from the Sahara, called *harmattan*, which blows during the dry season. Over the last 10 years, the region has experienced a minimum of 900 mm and a maximum of 1100 mm annual rainfall. The average temperature is 28° C with a minimum in the period December to February. The vegetation consists mainly of savannah and riparian forests along rivers. The local communities living around the APDs depend for their livelihood on food crops and cotton production, livestock farming, fishing, and trade in agricultural products. Markets exist for food crops and cotton, fish, vegetables, and livestock in Nikki District, the neighbouring districts, and in Nigeria (22 km from Nikki town) (Houngnihin, 2006).

Agro-pastoral dams in Nikki, Sakabansi, and Fombawi were selected because they differ in terms of size, river source, numbers of users, diversity of stakeholders involved, frequency of fishing, and number of crocodiles that live in the dams. The features of each dam (Kpéra et al., 2012) are presented in Table 5.1.

Table 5.1 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 / Oli	Niger / Oli	Niger / Oli
River	Sora	Samana	Kuena
Capacity (m^3)	257,000	200,000	170,000
Catchment basin (km^2)	120	20	2.4
Location of the dam from the town/village (km)	2	3	0.3
Number of crocodiles	< 20	> 100	> 300
Fishing frequency	Daily	Yearly	Yearly

5.3.2 Data collection

5.3.2.1 Water quality: physical, chemical, microbiological parameters

Water from the three agro-pastoral dams 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 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. 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. Direct

measurements were made in the field for parameters like temperature and pH (using PIONNER 10) and electrical conductivity of the water (using an OAKTON instrument), and the other physical and chemical parameters were analysed in the laboratory (see Table 5.2). 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 (Pradhananga et al., 2013) to the water analysis laboratory at the Energy and Water Service of Borgou and Alibori Districts (Direction Départementale de l'Energie et de l'Eau du Borgou et de l'Alibori) in Parakou (Benin) located approximately 117 km from Nikki District. Standard methods were used to analyse the water parameters (APHA, 1992; APHA, 1998).

Table 5.2 presents the methods used to analyse the physical and chemical parameters in the laboratory as well as the units of measurements.

To test the microbiological quality of the dam water, composite samples (made up of equal quantities of water from each of the three sampling sites) were collected in sterilized 1-litre bottles, labelled, kept in an ice chest, and transported the same day to the laboratory in Parakou (Pradhananga et al., 2012). 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 hours at 37°C using standard methods (APHA, 1992; APHA, 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; APHA, 1998). Unfortunately, pesticide levels could not be analysed because of lack of access to sufficiently sophisticated equipment.

Table 5.2 Techniques for physical and chemical parameters measurement/analysis

Parameters	Unit of measurement	Techniques/ Tools
Temperature (T)	º C	Thermometer (OAKTON)
Electrical conductivity (EC)	µS/cm	Conductivity meter (PIONEER 10)
pH	-	pH meter (OAKTON)
Nitrite (NO_2^-)	mg/l	
Nitrate (NO_3^-)	mg/l	
Ammonium (NH_4^+)	mg/l	Spectrophotometry
Phosphates (PO_4^{3-})	mg/l	(APHA, 1992)
Sulphates (SO_4^{2-})	mg/l	
Iron (Fe)	mg/l	
Chemical oxygen demand (COD)	mg/l	
Bicarbonates (HCO_3^-)	mg/l	
Chlorides (Cl^-)	mg/l	
Calcium (Ca^{2+})	mg/l	Titration
Magnesium (Mg^{2+})	mg/l	(APHA, 1992)
Total hardness	mg/l	

5.3.2.2 Fish diversity and biomass

- Experimental fishing

Experimental fishing was organized over five days, respectively, in Nikki, Sakabansi, and Fombawi APDs in April (before the annual fishing organized by Nikki Council), September and December 2011, and September 2012. According to the CeCPA, Communal Centre for Agriculture Promotion (*Centre Communal de Promotion Agricole*), fishermen were not allowed to use small dimensions of fishing nets to catch small fish in APDs. In our study, in order to catch all sizes of fish, two types of nets were used: 10 new gill nets (the length of each fishing gear is 100 m, the depth varies from 2.5 to 7.5 m), two old gill nets of the same dimensions borrowed from fishermen; and a seine net (2–3.5 cm, 30–75 m, and 3.5–5.6 m). Gill nets were installed in the evening at 18.00 and removed the next day in the morning at 7.00. The seine net was used from 16.00 to 19.00 every day (Ahouansou Montcho et al., 2009; Ahouansou Montcho et al., 2011) and was destined to collect small size fish that fishermen were not able to catch using their gill nets. Regarding big size fish, two or three

samples were collected and conserved in formalin solution, whereas all the small fish species caught were conserved in 10% formalin solution, which was prepared by diluting one part commercial formaldehyde with nine parts water (Vijaylaxmi et al., 2010). Photographs were taken prior to preservation since formalin decolorizes the fish colour after long preservation. Fish samples were brought to the Laboratory Hydrobiology and Aquaculture (LHA) at the University of Abomey-Calavi (UAC) in Benin for identification. Smaller fish were placed directly in the formalin solution, whereas larger fish were given an incision on the abdomen before they were fixed. Once at the laboratory, each fish sampled was washed with water and transferred into a bottle containing alcohol 90°C to avoid any decolouration (Ahouansou Montcho et al., 2011). They were labelled with serial numbers, exact location where collected, and date of collection. Identifications were based on identification keys for fish using the *Check-List of the Freshwater Fishes of Africa* (Paugy et al., 2003). We were assisted by taxonomic expertise from the LHA at UAC.

- *Fish biomass*

The biomass is not representative of the total fish biomass. Fishermen focus on catching large size fish. We considered only the catch from the 12 gill nets (10 new and 2 old gill nets) that selected large size fish to estimate fish biomass (production). Individual fish were identified and grouped per species. The specimens of each species were counted and weighed using an electronic scale (OHAUS brand). We then calculated (Ahouansou Montcho et al., 2011) a daily mean catch of big size fish (kg/day/APD) as the sum of the experimental fishing catches of the 5 days per dam / 5.

To estimate fish diversity, we considered all the fish caught with the two types of nets (seine net and gill net). The most common diversity measures are species richness (Colwell and Coddington, 1994), the Shannon-Weiner index (H') (Krebs, 1978), and the Pielou Evenness index (E) (Pielou, 1966). These measures are defined as follows:

- *Species richness*

Species richness (S) is the number of different species represented in an ecological community, landscape, or region. Species richness is simply a count of species, and it does not take into account the abundances of the species or their relative abundance distributions (Colwell and Coddington, 1994).

- *Shannon-Weiner index (H')*

H' = -Σ [Pi $\log_2$ (Pi)] where, Σ = Sum; $P_i = N_i/N$ where Ni = Number of individuals of the species i and N = Total number of individuals of all species in the sample. The units of the Shannon-Weiner index depend on the log used. For $\log_2$, the unit is bits/individual. *H'* is constrained between 1 and 5 bits/individual. It is exclusively high (in the case of large and complex populations) when all species occur in similar numbers of individuals and low when the sample contains a single species. In addition, several authors have commented that low values are regarded as indicators of pollution (Jørgensen et al., 2005).

- *Pielou Evenness index* (E')

Species evenness (E') is a measure of how evenly abundance is distributed among the species that exist in the community. E' refers to how close in numbers each species is in an environment (Pielou, 1966). $E' = H'/\log_2 S$, where *H'* is the value of the Shannon value, and S the total number of species. E' takes values between 0 and 1, where 1 represents a community with perfect evenness and decreases to zero as the relative abundances of the species diverge from evenness.

5.3.3 Data analysis for physical and chemical water parameters

A full 3 x 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 3.1.2 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.

5.4 Results

5.4.1 Physical, chemical, and microbiological quality of APD water

5.4.1.1 Variation in physical and chemical water parameters

Results of the ANOVA with repeated measures (Table 5.3) 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 x 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 5.3), 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 ($p < 0.05$) (Appendix Table A5.1).

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.

Table 5.3 F-values and probability levels from the analysis of variance with repeated measures on the physical and chemical water parameters

Parameters	Dam		Season		Dam x Season	
	df	F-values	df	F-values	df	F-values
T (º C)	2	0.38 ns	2	1486.67***	4	2.79ns
EC (µS/cm)	2	987.11***	2	3064.71***	4	879.58***
pH	2	29.32***	2	47.24***	4	46.18***
NO_2^- (mg/l)	2	25.26**	2	99.33***	4	6.52**
NO_3^- (mg/l)	2	1.90ns	2	39.13***	4	4.43*
NH_4^+ (mg/l)	2	72.10***	2	154.89***	4	109.96***
PO_4^{3-} (mg/l)	2	380.41***	2	147.88***	4	262.18***
SO_4^{2-} (mg/l)	2	14.29**	2	76.55***	4	14.36***
Fe (mg/l)	2	20.28**	2	16.04***	4	27.30***
COD (mg/l)	2	177.46***	2	400.96***	4	103.84***
HCO_3^- (mg/l)	2	8.80*	2	54.87***	4	15.04***
Cl^- (mg/l)	2	40.09***	2	168.66***	4	11.33***
Ca^{2+} (mg/l)	2	182.65***	2	315.73***	4	203.78***
Mg^{2+} (mg/l)	2	3.03ns	2	61.45***	4	47.10***
Hardness (mg/l)	2	106.35***	2	48.71***	4	109.23***

Legend: df=degree of freedom; F=Fisher

*, ** and *** indicate significant effects at $p < 0.05$, $p < 0.01$, $p < 0.001$, respectively.

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 (see Appendix Table A.5.1 1).

5.4.1.2 Correlation between physical and chemical parameters

In Figure 5.2, 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).

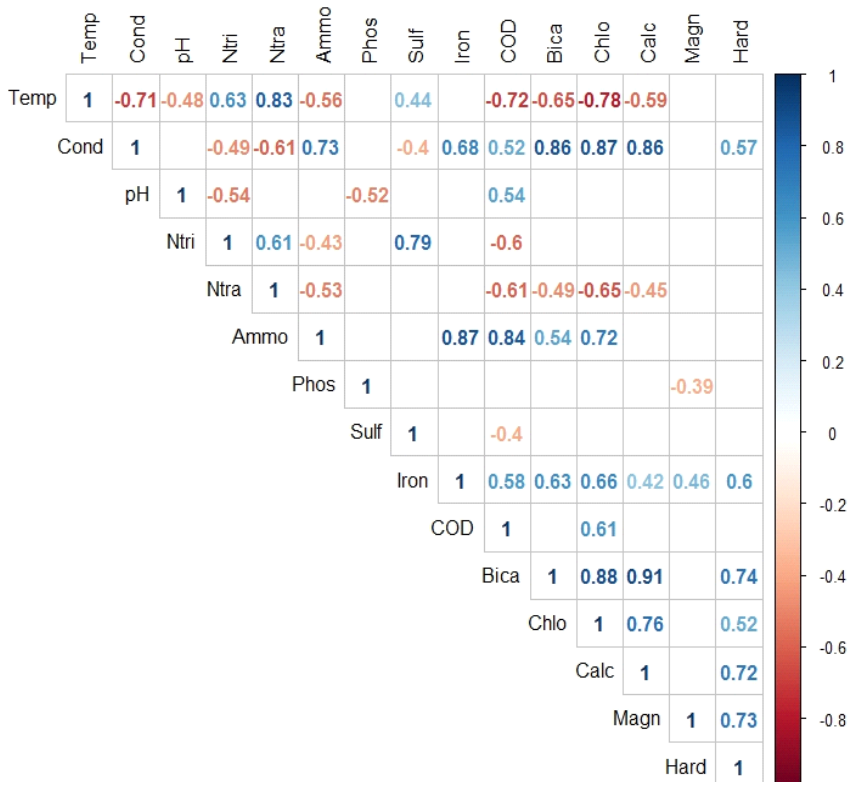

Figure 5.2 Correlation between physical and chemical water parameters

Caption: Blue indicates negative correlations. Red indicates positive correlations. The darker the colour, the stronger the correlation. 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.

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 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.

5.4.1.3 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 5.4). 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 water (see Appendix Tables A.5.2; A.5.3, A.5.4).

5.4.1.4 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 5.5

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.

Table 5.4 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		
Para-meters	Norms (mg/l)	June	Sept	Dec	June	Sept	Dec	June	Sept	Dec
pH	Benin (6.5–8.5)	6ns 0ns	6.42ns -16.25ns	6ns 0ns	7.46ns 0.57ns	6ns 0ns	17.32ns -17.32ns	11.72ns -10.96ns	6ns 0ns	**-5.20*** -39.84ns
	WHO (6.5–8.5)	6ns 0ns	6.42ns -16.25ns	6ns 0ns	7.46ns 0.57ns	6ns 0ns	17.32ns -17.32ns	11.72ns -10.96ns	6ns 0ns	**-5.20*** -39.83ns
NO_2^-	Benin (3.2)	-6.79ns	**6.65****	-6.27ns	0ns	1.45ns	0ns	-20.16ns	**7.26****	0.42ns
	WHO (3)	-3.30ns	**7.58****	-3.00ns	0ns	4.29ns	-905.10ns	-17.48ns	**8.29****	1.07ns
NO_3^-	Benin (45)	-10.16ns	2.12ns	**5.50***	-12.32ns	**4.30***	1.73ns	-1.64ns	29.44***	0.84ns
	WHO (50)	-17.98ns	0.59ns	**3.65***	-20.70ns	1.77ns	-0.39ns	-2.70ns	**18.36****	-3.36ns
Fe	Benin (0.3)	**12.60****	**78.53****	6ns	**7.85****	**58.89*****	**16.44****	**5.44***	**20.03****	**7.45****
COD	Benin (125)	-49.78ns	-45.17ns	-54.60ns	**9.35****	-18.72ns	-19.39ns	**11.77****	-19.08ns	-45.89ns

*, **, *** significant effects at $p < 0.05$, $p < 0.01$ and $p < 0.001$ respectively; ns=non-significant; Significant effects are bold; Sept= September; Dec= December; t-value (t): from Student's t-test; Wilcoxon-value (v): from Wilcox.test

Table 5.5 Microbiological analysis of water from Nikki, Sakabansi, and Fombawi APDs per period

Bacteria	Nikki			Sakabansi			Fombawi		
	June	Sept	Dec	June	Sept	Dec	June	Sept	Dec
Total Coliform	28	CL	1056	163	456	488	470	796	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	+	-	-	-	-	-	-	-	+

Legend: Numbers represent the counting of the developed colonies after incubation for 24 hours

- = absence; + = presence; CL = countless (so many as to be impossible to count); Sept = September; Dec = December

5.4.2 Fish diversity and biomass

5.4.2.1 Fish diversity in agro-pastoral dams

Table 5.6 presents fish species, richness, abundance, and diversity in Nikki, Sakabansi, and Fombawi.

A total of 7,104 individual fish were caught in the three APDs. The total fish catch in numbers in Fombawi is the highest (43%), followed by Sakabansi (29%) and Nikki (28%). All the fish caught in the three APDs belong to 20 species (S = 20) grouped in 14 genera and eight families. Eight (8) species are common to the three dams. Species richness is higher in Nikki (18) than in Fombawi (11) and Sakabansi (10). The Shannon index shows that Nikki and Sakabansi have almost the same diversity (respectively, H'=1.93 ± 0.06 and H'=1.84 ± 0.05), and Fombawi has the lowest (H'=1.22 ± 0.16). The Pielou Evenness index in the three APDs is in the normal range, i.e. between 0 and 1.

Table 5.6 Fish species list, richness, abundance, and diversity in Nikki, Sakabansi, and Fombawi

Families Species	Nikki	Sakabansi	Fombawi	Total
Mormyridae				
Mormyrus hasselquistii (Valenciennes, 1846)			4	4
Marcusenius senegalensis (Steindachner, 1870)	16		53	69
Hepsetidae				
Hepsetus odoe (Bloch, 1794)	64			64
Alestidae				
Brycinus nurse (Rüppell,1832)	12	411		423
Micralestes occidentalis (Günther,1899)	53			53
Micralestes pabrensis (Roman, 1966)	82			82
Cyprinidae				
Raiamas senegalensis (Steindachner, 1870)	18			18
Labeo parvus (Boulenger, 1915)	10			10
Barbus baudoni (Boulenger, 1918)	2			2
Barbus macinencis (Daget, 1954)		2	14	16
Barbus macrops (Boulenger, 1911)	175	35	1	211
Barbus callipterus (Boulenger, 1907)	620	412	97	1129
Barbus nigeriensis (Boulenger, 1902)	70	181	80	331
Schilbeidae				
Schilbe intermedius (Rüppell, 1832)	234	116	171	521
Clariidae				
Clarias gariepinus (Burchell, 1822)	3	3	12	18
Clarias anguillaris (Linnaeus, 1758)	52	71	218	341
Poecilliidae				
Micropanchax pfaffi (Daget, 1954)	3			3
Cichlidae				
Hemichromis bimaculatus Gill, 1862	7			7
Tilapia mariae (Boulenger, 1899)	5	282	396	683
Oreochromis niloticus (Linnaeus, 1758)	562	543	2014	3119
Diversity				
N=Total number of individuals	1988	2056	3060	7104
Species richness	18	10	11	20
Shannon-Weiner index (H') ±SD	1.93 ± 0.06	1.84 ± 0.05	1.22 ± 0.16	-
Pielou Evenness index (E') ±SD	0.46 ± 0.01	0.55 ± 0.02	0.35 ± 0.05	-

Check-List of the Freshwater Fishes of Africa, (CLOFFA, Paugy et al., 2003); Species in bold are market size fish species; SD = Standard of Deviation

In the three APDs, six species are abundant in number (see Table 5.7). *O. niloticus* is the most abundant everywhere. Some species are represented by few individuals (fewer than 10). *C. gariepinus* is rare everywhere, similar to *T. mariae* in Nikki APD. *Barbus baudoni, Micropanchax pfaffi,* and *Hemichromis bimaculatus* represented by, respectively, two, three, and seven individuals are observed only in Nikki; *Mormyrus hasselquistii* is found only in Fombawi.

Table 5.7 Proportion (%) of abundant fish species in Nikki, Sakabansi, and Fombawi

Species	Nikki (%)	Sakabansi (%)	Fombawi (%)
Brycinus nurse	1	20	0
Barbus callipterus	31	20	3
Schilbe intermedius	11	6	6
Clarias anguillaris	3	3	7
Tilapia mariae	<1	14	13
Oreochromis niloticus	28	26	66

According to fishermen and local communities in Nikki, Sakabansi, and Fombawi, fish species with a market value are large size species especially: *C. anguillaris*, *C. gariepinus*, *O. niloticus*, and *T. mariae.* Thus, they are targeted species for fishing. These marketable species represent, respectively, 31%, 44%, and 86% of the total fish population in Nikki, Sakabansi, and Fombawi.

O. niloticus is represented everywhere, even in Nikki where daily fishing occurs. It represents 90% of the marketable fish in Nikki and 76% in Fombawi. *T. gariepinus* contributes little to marketable fish anywhere; *T. mariae* is almost non-existent in Nikki (see Table 5.8.). According to Nikki Council, there is no problem with the marketing of fish. In contrast, the council is not able to satisfy the local communities' high demands in terms of fish quantity.

Table 5.8 Proportion (%) of marketable fish species in Nikki, Sakabansi, and Fombawi

Species	Nikki (%)	Sakabansi (%)	Fombawi (%)
Clarias gariepinus	<1	<1	<1
Clarias anguillaris	8	8	15
Tilapia mariae	1	31	15
Oreochromis niloticus	90	60	76

5.4.2.2 Fish biomass in APDs

Table 5.9 presents the daily mean catches per period in Nikki, Sakabansi, and Fombawi APDs.

Table 5.9 Experimental fish catches using gill nets over five days of fishing in each season and the daily average catches per period in Nikki, Sakabansi, and Fombawi APD

APD	April 2011	September 2011	December 2011	September 2012	Total
			Experimental catches (kg)		
Nikki	27.08	48.36	41.50	10.90	127.82
Sakabansi	51.28	4.45	11.55	24.88	92.16
Fombawi	244.49	87.76	27.51	16.57	**376.34**

During the study, Fombawi recorded the highest experimental fish biomass caught followed by Nikki and Sakabansi. Comparison of the experimental catches per period reveals that the highest catch was recorded in April 2011 for Fombawi and Sakabansi. However, the experimental catch from Fombawi is five times greater than that from Sakabansi. In Nikki, the highest catch was recorded in September 2011 and equalled half of the catch in Fombawi in September 2011. The lowest catch is recorded for Sakabansi in September 2012, for Fombawi in December 2011, and for Nikki in September 2012.

According to fishermen, the period of maximum catch is observed in April (peak of the dry season) when the dam water level decreases, and the lowest catch occurs in September, corresponding to the peak of the rainy season.

5.5 Discussion

5.5.1 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 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; Herbeck et al., 2013; sssKpieta 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 (Sinsin, 1994) – 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) (Suanon et al., 2013; 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 upstream parts of a watershed can have effects on downstream users because of a continuum of users throughout a watershed, this suggests that water quality upstream 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, 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/100ml 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 (MA, 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 (MA, 2005), *supporting services* (nutrient cycling), and *cultural services* that provide recreation (safe swimming and bathing) (Bastian et al., 2013).

5.5.2 Fish diversity and fish biomass in the APDs

The Nikki, Sakabansi, and Fombawi APDs are fed, respectively, by the temporary rivers Samana, Sora, and Kouena that are part of the Oli sub-watershed (Brauman et al., 2007) of the Niger watershed (Azonsi et al., 2008). Fish species richness for the three APDs is low (S = 20

species) compared to Pendjari River (in the Volta watershed) in Northern Benin (S = 131 species) (Ahouansou Montcho, 2011), Ouémé River (in the Ouémé watershed) in Southern Benin (S = 122 species) (Lalèyè et al., 2004), and in Benin as a whole (S = 234 species) (Chikou, 1997). The 20 species in the APDs are native, except *O. niloticus* which was introduced in Benin in 1970 to improve fish farming (Lalèyè et al., 2004). Fewer fish species occur in APDs than rivers, probably because the APDs act as a sink, i.e. after the rainy season ends no water flows in and out. This calls for research in APDs to study biodiversity of fish upstream of the dams to get evidence of loss of biodiversity. Furthermore, the lower turbidity in dams helps predators to be more effective in hunting prey. The difference in species richness in the three APDs may also be attributed to the size of the water area (Hugueny, 1989), which is larger in Nikki than in Sakabansi and Fombawi, and thus favourable to the movement and the growth of fish species.

The daily fishing in Nikki may have negatively affected diversity. As daily fishing is selective and focuses on large and marketable fish species (*Cichlidae* and *Clariidae*), this allows juvenile fish to reproduce before harvesting (Sissenwine and Shepherd, 1987). Old and large individuals are most responsible for reproduction (Birkeland and Dayton, 2005), and selective fishing alters the composition of fish populations, ecosystem structure, and biodiversity, and intensifies fluctuations in population abundance (Anderson et al., 2008, Garcia et al., 2012), in turn increasing the risks associated with low abundance.

In terms of diversity, although the three APDs are in the Niger watershed, Nikki has a higher score for species richness, with Sakabansi and Fombawi scoring almost the same for species richness. Cottenie et al. (2001) argued that waters located within the same watershed can differ in their trophic structure and biotic and abiotic compositions and interactions. The Pielou Evenness index in the three APDs is in the normal range (0 and 1). The lowest Pielou index is recorded for Fombawi. The low species richness in Fombawi is confirmed by the Shannon and Pielou Evenness index. It is common knowledge that a community is less diverse where species are unevenly abundant (Uttah, 2013). *O. niloticus* represents 66% of the total number of fish in Fombawi, 28% in Nikki, and 26% in Sakabansi. The fingerlings of *O. niloticus* introduced in Nikki by PADPPA in 2005 may militate in favour of Nikki (PADPPA, 2005), but the daily fishing in Nikki against the yearly fishing in Sakabansi and Fombawi should have reduced *O. niloticus* numbers in Nikki in the same way as *C. gariepinus* everywhere and *T. mariae* in Nikki. However, *O. niloticus* is well known for its fast growth, successful reproduction, and ability to feed at different trophic levels (Peterson et al., 2005; Ahouansou Montcho and Lalèyè, 2008), thus escaping fishing pressure. The scarceness of *C.*

gariepinus everywhere and of *T. mariae* in Nikki may be imputed to crocodiles. Fishermen claim that crocodiles prey on marketable fish species. Although fish are the most important prey for crocodiles (Platt et al., 2006; Wallace and Leslie, 2008), it is also a fact that crocodile droppings contain critically important nutrients that contribute to renewing the fish stock (van der Ploeg et al., 2011a). In our study, the ratios of large size fish species/fish biomass are 622/127.82 for Nikki, 899/92.16 for Sakabansi, and 2640/376.34 for Fombawi, indicating that there are more large fish in Sakabansi (> 100 crocodiles) than in Fombawi (> 300 crocodiles). This could probably elucidate the high biomass of large fish observed in Sakabansi because of more nutrients produced by adult crocodiles in comparison to Fombawi which has more sub-adult crocodiles but producing fewer nutrients.

As for scarce *C. gariepinus*, although widely tolerating poor water quality conditions (Adeyemi, 2015), the accumulation of iron in this species' organs and tissues (Singh et al., 2012; Ohimain et al., 2014) causes high mortality of *C. gariepinus* fingerlings (Ohimain et al., 2014).

Overall, any loss of resilience and change in the APD ecosystem equilibrium state may affect the services provided by the presence of fish: *provisioning services* (fish), *regulating services* (fish species richness and biodiversity), *supporting services* (nutrient cycling), and *cultural services (*recreation benefits like fishing).

5.6 Conclusions and recommendations

Agro-pastoral dam ecosystems, by providing numerous services to their users, contribute directly or indirectly to users' 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.

As regards fish diversity, only 20 fish species have been identified in the three APDs compared to 122 to 234 species in Benin rivers. Although the three APDs are in the Niger watershed, fish diversity is higher in Nikki than in Fombawi and Sakabansi, which have the same species richness. Among these species, four large size species are associated with market value, thus targeted for fishing: *C. anguillaris, C. gariepinus, O. niloticus,* and *T. mariae.* These marketable species are more abundant in Fombawi than in Sakabansi and Nikki. *O. niloticus* is the only prominent large species that is not part of the natural population. *O. niloticus* represents 90% of marketable fish in Nikki, 60% in Sakabansi, and 76% in Fombawi APDs. *C. gariepinus* is almost absent in the three APDs, and in Nikki *C. gariepinus* and *T. mariae* are rare.

This first study of APD water quality and fish diversity in Benin yielded results for the three APDs studied and was limited to a period of one year. No comparable measurements for rivers and other dams were available for the larger watershed. Important research items to be addressed in the future include:

- To understand the long-term functioning of dams' ecosystem services, the up- and downstream water, fish, and wildlife ecology and agriculture should be studied over longer periods of time, also to account for climate change and land use change.
- The infestation of APD water by infectious bacteria necessitates follow up on the epidemiology of waterborne diseases that may occur in the villages using the APDs.
- Water quality, including pesticide use, should be continuously monitored to ensure that council regulations are met.
- APDs' fish species stock and the species and the biomass of fish predated by crocodiles depending on their ages should be regularly evaluated to adjust fishing selection and frequency.
- Inventories should be taken of all APDs in Benin, starting in Nikki District, to compare utilization and management practices and to exchange best practices.

The approach to sustainable APD ecosystem management includes (i) implementation of best agricultural practices; (ii) management that avoids agricultural runoff, effluent, sewage dumps, pollutants, erosion, and siltation; (iii) rigorous compliance with regulations and rules and application of sanctions in the event of infraction; and (iv) adjustment of fishing. To ensure healthy ecosystems and APD sustainability, we suggest:

- Raising the awareness of local communities and activating Nikki council with respect to the implementation of best agricultural management practices around APDs, including the control and monitoring of fertilizer and pesticide use around APDs, assessing the suitability of pesticides for vegetable production, compliance with regulations about cropping in the close vicinity of the dams, the treatment of effluent emanating from Nikki, Sakabansi, and Fombawi.
- Nikki Council should monitor the fish populations and adjust fishing frequency and selective fishing to maintain a diverse, healthy, and productive fish population.
- The Ministry of Agriculture, Livestock Production and Fisheries (MAEP) in collaboration with the Ministry of Mines, Energy, and Water (MMEE: *Ministère des Mines, de l'Energie et de l'Eau*) should manage watersheds by monitoring ecosystem services like water quality and fish biodiversity in rivers and APDs to ensure food security.

Appendix

Table A.5.1 Mean and variability of physical and chemical water parameters in Nikki, Sakabansi and Fombawi APDs in different seasons

Para-meters	Nikki APD						Sakabansi APD						Fombawi APD					
	June		September		December		June		September		December		June		September		December	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
T	25.30B	0.06	28.17A	0.09	28.23A	0.03	25.30C	0.06	28.30A	0.00	27.90B	0.12	25.30B	0.06	28.20A	0.00	28.13A	0.17
EC	165.33A	0.88	63.67C	1.20	74.33B	0.33	62.33B	1.45	58.33C	0.88	71.33A	0.33	210.67A	2.40	58.33C	0.88	80.33B	2.67
pH	7.00B	0.00	7.07B	0.09	7.70A	0.00	8.67A	0.29	6.97B	0.03	7.50B	0.06	7.53A	0.09	6.97B	0.03	6.20C	0.06
NO_2^-	2.81B	0.05	4.63A	0.21	2.82B	0.06	2.01B	0.00	3.66A	0.32	2.00B	0.00	1.70C	0.08	4.60A	0.19	3.33B	0.31
NO_3^-	38.51B	0.64	51.92A	3.26	59.81A	2.69	37.77B	0.59	53.49A	1.98	49.08A	2.35	37.23B	4.73	58.29A	0.45	46.00B	1.19
NH_4^+	0.34B	0.04	0.66A	0.01	0.22C	0.00	0.66A	0.01	0.21C	0.01	0.35B	0.04	2.04A	0.16	0.31B	0.00	0.43B	0.02
PO_4^{3-}	0.21B	0.02	0.33A	0.01	0.13C	0.03	0.29A	0.03	0.30A	0.01	0.16B	0.04	1.11B	0.07	0.37C	0.00	2.21A	0.08
SO_4^{2-}	1.00B	0.00	4.67A	0.33	0.67B	0.33	0.67B	0.33	2.33A	0.33	0.00B	0.00	0.00B	0.00	1.67A	0.33	1.33A	0.33
Fe	1.14B	0.07	2.02A	0.02	1.10B	0.01	0.42C	0.02	1.66A	0.02	0.99B	0.04	5.73A	1.00	1.77B	0.07	0.61B	0.04
COD	52.67A	1.45	56.00A	1.53	45.67B	1.45	233.00A	11.55	61.67B	3.38	63.33B	3.18	294.33A	14.38	64.33B	3.18	72.00B	1.15
HCO_3^-	54.90A	3.52	30.50B	0.00	26.43B	2.03	25.42B	4.57	33.55A	0.00	24.40B	0.00	53.88A	3.66	29.48B	1.02	20.33C	2.03
Cl^-	17.75A	0.00	10.65B	0.00	6.51C	1.65	11.24A	0.59	8.87B	0.00	5.33C	0.00	21.30A	0.00	10.65B	0.00	8.28C	1.18
Ca^{2+}	18.97A	0.96	4.81B	0.00	4.81B	0.00	1.60B	0.00	5.34A	0.27	5.08A	0.27	13.36A	0.27	4.81B	0.00	3.48C	0.27
Mg^{2+}	4.05B	0.33	9.24A	0.28	4.53B	0.16	1.46B	0.00	8.76A	0.56	9.40A	1.06	8.27A	0.56	9.40A	0.33	1.13B	0.16
Hardness	65.33A	0.67	50.00B	1.15	30.67C	0.67	10.00B	0.00	49.33A	2.91	51.33A	4.81	67.33A	1.76	50.67B	1.33	13.33C	0.67

SE = standard error; within each APD, values followed by the same letter in the same line are not significantly different as established by the Student-Newman-Keuls.test ($p < 0.05$)

Table A.5.2 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

Parameters	Norms (mg/l)	June	September	December
EC (µs	Benin	–	-	–
	WHO (800)	-719.64ns	-612.67ns	0ns
pH	Benin (6.5–8.5)	[6ns ; 0ns]	[6.42ns ;-16.25ns]	[6ns; - 0ns]
	WHO (6.5–8.)]	[6ns ; 0ns]	[6.42ns ;-16.25ns]	[6ns; - 0ns]
NO_2^-	Benin (3.2)	-6.79ns	6.65**	-6.26ns
	WHO (3)	-3.30ns	7.58**	-3.00ns
NO_3^-	Benin (45)	-10.16ns	2.12ns	5.50*
	WHO (50)	-17.98ns	0.59ns	3.65*
NH_4^+	Benin (50)	-1353.30ns	0ns	0ns
	WHO	–	–	–
PO_4^{3-}	Benin (5)	-230.10ns	0ns	-159.41ns
	WHO	–	–	–
SO_4^{2-}	Benin (500)	0ns	0ns	0ns
	WHO (250)	0ns	0ns	0n
Fe	Benin (0.3)	12.60**	78.54**	6ns
	WHO (0.3)	12.60**	78.54**	6ns
COD	Benin (125)	-49.78ns	-45.17ns	-54.60ns
	WHO	–	–	–
Cl^-	Benin (250)	0ns	0ns	-155.67ns
	WHO (250)	0ns	0ns	-155.67ns
Ca^{2+}	Benin (100)	-84.27ns	0ns	0ns
	WHO (75)	-58.27ns	0ns	0ns
Mg^{2+}	Benin (50)	0ns	-145.55ns	0ns
	WHO (30)	-74.12ns	0ns	0ns
Hard	Benin (200)	0ns	-129.90ns	0ns
	WHO (300–500)	[0ns ; 0ns]	[-216.5ns;-389.71ns]	[0ns ; -704ns]

*, **, *** significant effects at $p < 0.05$, $p < 0.01$ and $p < 0.001$ respectively; ns=non-significant; t-value (t): from Student's t-test; Wilcoxon-value (v): from Wilcox.test

Table A.5.3 T-values/v-values and probability levels from the conformity test of the physical and chemical water parameters to Benin and WHO norms in Sakabansi

Para-meters	Norms (mg/l)	June	September	December
EC (µs	Benin	–	-	–
	WHO (800)	-507.70ns	-840.97ns	0ns
pH	Benin (6.5;8.5)	[7.46ns ; 0.57ns]	[6ns ; 0ns]	[17.32ns ; -17.32ns]
	WHO (6.5;8.5)	[7.46ns ; 0.57ns]	[6ns ; 0ns]	[17.32ns ; -17.32ns]
NO_2^-	Benin (3.2)	0ns	1.45ns	0ns
	WHO (3)	0ns	4.29ns	-905.10ns
NO_3^-	Benin (45)	-12.32ns	4.30*	1.73ns
	WHO (50)	-20.70ns	1.77ns	-0.39ns
NH_4^+	Benin (50)	-4303.36ns	-3342.83ns	-1333.32ns
	WHO	–	–	–
PO_4^{3-}	Benin (5)	-146.52ns	-323.70ns	-119.27ns
	WHO	–	–	–
SO_4^{2-}	Benin (500)	-1498ns	0ns	0ns
	WHO (250)	0ns	0ns	0ns
Fe	Benin (0.3)	7.85**	58.89***	16.44**
	WHO (0.3)	7.85**	58.89***	16.44**
COD	Benin (125)	9.35**	-18.72ns	-19.39ns
	WHO	–	–	–
Cl^-	Benin (250)	0ns	0ns	0ns
	WHO (250)	0ns	0ns	0ns
Ca^{2+}	Benin (100)	0ns	0ns	0ns
	WHO (75)	0ns	0ns	0ns
Mg^{2+}	Benin (50)	0ns	-73.27ns	-38.22ns
	WHO (30)	0ns	-37.74ns	-19.39ns
Hard	Benin (200)	0ns	-51.85ns	-30.92ns
	WHO [300 ;500]	[0ns ; 0ns]	[86.26ns ; -155.08ns]	[-51.72ns ; -93.33ns]

*, **, *** significant effects at $p < 0.05$, $p < 0.01$ and $p < 0.001$ respectively; ns=non-significant; t-value (t): from Student's t-test; Wilcoxon-value (v): from Wilcox.test

Table A.5.4 T-values/v-values and probability levels from the conformity test of the physical and chemical water parameters to Benin and WHO norms in Fombawi

Para-meters	Norms (mg/l)	June	September	December
EC (µs	Benin	–	-	–
	WHO (800)	-245.18ns	-840.97ns	0ns
pH	Benin [6.5;8.5]	[11.72ns ;-10.96ns	[6ns ; 0ns]	[-5.20*; -39.84ns]
	WHO [6.5;8.5]	[11.72ns; -10.96ns	[6ns; 0ns]	[-5.20*; -39.83ns]
NO_2^-	Benin (3.2)	-20.16ns	7.26**	0.42ns
	WHO (3)	-17.48ns	8.29**	1.07ns
NO_3^-	Benin (45)	-1.64ns	29.44***	0.84ns
	WHO (50)	-2.70ns	18.36**	-3.36ns
NH_4^+	Benin (50)	-309.38ns	0ns	-2644.68ns
	WHO	–	–	–
PO_4^{3-}	Benin (5)	-56.43ns	0ns	-34.52ns
	WHO	–	–	–
SO_4^{2-}	Benin (500)	0ns	0ns	0ns
	WHO (250)	0ns	0ns	0ns
Fe	Benin (0.3)	5.44*	20.03**	7.45**
	WHO (0.3)	5.44*	20.03**	7.45**
COD	Benin (125)	11.77**	-19.08ns	-45.89ns
	WHO	–	–	–
Cl^-	Benin (250)	0ns	0ns	0ns
	WHO (250)	0ns	0ns	0ns
Ca^{2+}	Benin (100)	0ns	0ns	0ns
	WHO (75)	0ns	0ns	0ns
Mg^{2+}	Benin (50)	-74.51ns	0ns	0ns
	WHO (30)	-38.80ns	0ns	0ns
Hard	Benin (200)	-75.21ns	0ns	0ns
	WHO [300 ; 500]	[-131.91ns ; -245.30ns]	[0ns ; 0ns]	[0ns ; 0ns]

*, **, *** significant effects at $p < 0.05$, $p < 0.01$ and $p < 0.001$ respectively; ns=non-significant; t-value (t): from Student's t-test; Wilcoxon-value (v): from Wilcox.test

CHAPTER 6

General discussion

6.1 Introduction

Water reservoirs constructed to enhance agricultural sector activities in Benin, agro-pastoral dams (APDs), are aquatic ecosystems associated with a range of activities such as fishing, vegetable production, food cropping and cotton farming, swimming, bathing, washing, watering livestock, collection of water for drinking and household use, collection of water for house and road construction, and small business water use. They play a vital role in generating income for local communities and contributing to food security. This thesis highlights the complexity of managing APDs that are intensively used by different stakeholders.

This is the first study to focus on dam use and management in Northern Benin (Nikki District). For sound and sustainable APD management that supports the improvement of local communities' livelihoods, the results of the study show that physical, social, and institutional changes are needed in the management of dam water resources in the three studied APDs, one each in Nikki town, Sakabansi, and Fombawi. To understand the underlying ecological mechanisms, further work over a longer period is needed. In addition, more knowledge and understanding of the functioning of APDs and associated watersheds is required to contribute to dam management and to provide guidance for district councils – charged with the management of APDs in Benin – to develop and implement policy measures.

The purpose of this research was to shed light on how stakeholders use and manage the APDs. The specific research objectives of this thesis are:

1) To identify physical, social, and institutional impediments and opportunities in relation to the use and management of agro-pastoral dams (Chapters 2, 3, 4, 5);
2) To sharpen our understanding of how local stakeholders frame the presence of crocodiles, and the formal and informal institutions that people use to cope with them (Chapter 3);
3) To examine the challenges for smallholder vegetable producers when they are using the agro-pastoral dams (Chapter 4);
4) To analyse the impact of sharing agro-pastoral dam ecosystem services on water quality, fish diversity, and fish biomass (Chapter 5).

Because of the multi-purpose use of APD ecosystem services, the multiplicity of the stakeholders involved, and the manifold tensions between them relating to APD use and the management, this research started from an integral ecology (IE) framework. The IE framework consists of a set of the most comprehensive and inclusive perspectives that help to

better understand APDs as a complex social-ecological system, whose components respond to the state of the system as a whole (Ostrom, 2011).

In this last chapter, the main research findings are integrated in harmony with the four terrains of the IE framework, followed by a discussion about a number of crosscutting issues that have emerged from the separate studies. The chapter ends with recommendations for policy development and practices for integral APD management and suggestions for a future research agenda.

6.2 Synopsis of the main findings

The main findings are presented according to the four irreducible perspectives represented by the four quadrants of the IE framework (Figure 6.1). Research on several categories of stakeholders – crop and cotton farmers, herders, water collectors for household and small business, fishermen, and recreation participants – has not been carried out in similar detail as for the vegetable producers.

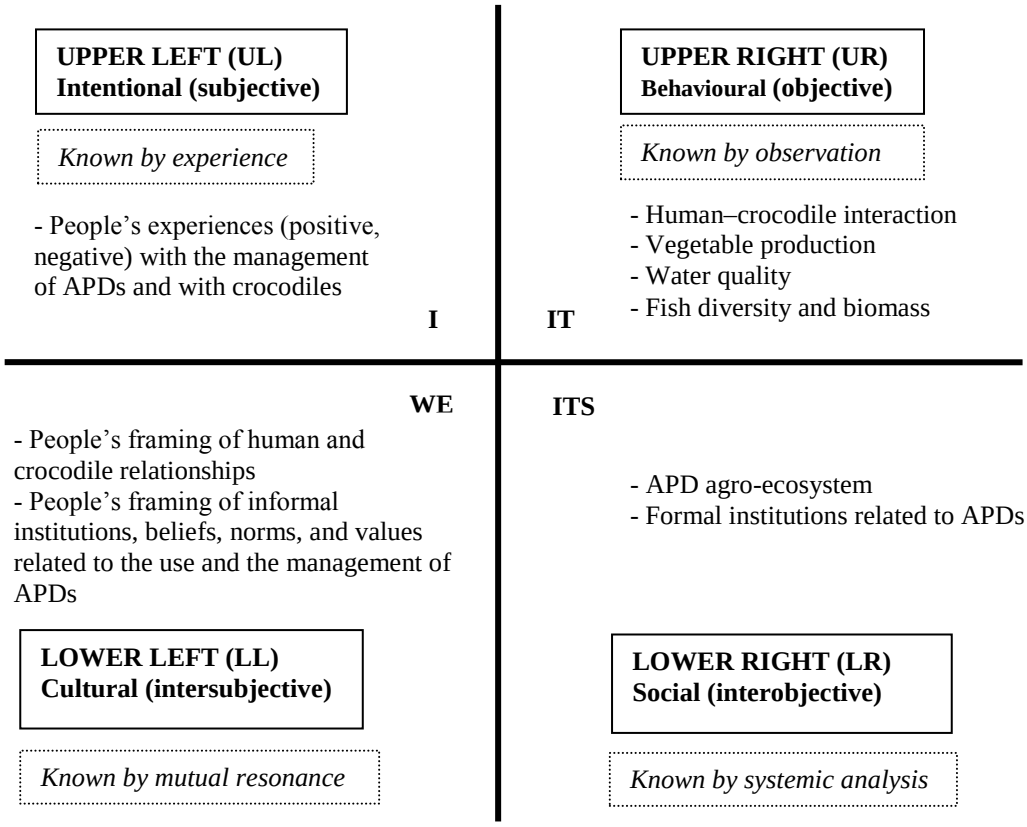

Figure 6.1 The four quadrants of integral ecology theory applied to APDs in relation to relevant study objects (Adapted from Esbjörn-Hargens and Zimmerman, 2009)

6.2.1 Conflicts and tensions

The terrain of experiences (the upper left quadrant) refers to local communities' experiences with APDs and how they address problems that emanate from sharing the APD ecosystem services. Two main categories of stakeholders are involved in the use and management of the dams: (1) the users of the dams' ecosystem services (herders, vegetable farmers, food crop and cotton farmers with a farm near the dams, daily users of the dams, fishermen, and crocodiles) and (2) government officers at local and national level who manage the APDs. The involvement of diverse human stakeholders – with different interests, backgrounds, knowledge, and assumptions – and non-human stakeholders (mainly crocodiles and livestock) makes the APD a complex system. Stakeholders experience problems that principally have to do with siltation of dams, decrease in water quality, improper land use, invasion of APDs by aquatic plants, deforestation of the water edge, herder–farmer conflicts, and human–crocodile conflicts (Chapter 2). They interpret the causes, effects, and solutions to the problems differently. In addition to their experiences, the stakeholders have learned to live with crocodiles and their damage, which is prejudicial to dam infrastructures, fishing nets, and domestic animals and humans. Nevertheless, stakeholders give credit to crocodiles' ecological role in maintaining water during drought (Chapters 2 and 3).

Nikki Council – charged with the management of the Nikki District APDs – has faced several tensions in relation to (i) the relocation of Nikki vegetable producers to downstream, (ii) the displacement of farmers farming within a radius of 1000 m of the APDs, (iii) users and CoGes (CoGes: *Comité de Gestion du barrage*) who blame the council for prejudiced mismanagement of dam income, and (iv) damaging farmers crops and causing the farmer–herder conflicts (Chapter 2). In addition, the dams' ecosystem services' users (herders, vegetable farmers, food crop and cotton farmers with a farm near the dams, daily users of the dams, fishermen, and crocodiles) in taking care of their own interests have created and maintained different tensions amongst themselves and with local government in relation to APD use and management.

6.2.2 Constructing norms and informal rules

The terrain of culture (the lower left quadrant) unravels the informal institutions that have been socially constructed and shared, as well as the way they are discursively and collectively reconstructed. These informal institutions refer to: (i) rules negotiated between the council

and users of the dams' ecosystem services to guide stakeholders in using and managing APDs (Chapter 2) and (ii) rules enabling interaction with crocodiles, which are an integral part of the local culture of Fombawi (Chapters 2 and 3). The first rules emphasize: (1) fees for watering transhumant livestock and house construction, (2) livestock movement corridors to access APDs, (3) relocation of farms within 1000 m of an APD's edge, (4) relocation of vegetable gardening downstream of APDs, (5) ban on cleaning, washing, and swimming, (6) fishing conditions, (7) commitment of income from the dams to local development. Although well known by all the users, these rules are not spontaneously or collectively obeyed. In contrast, the informal rules vis-à-vis the way to deal with crocodiles in Fombawi – requiring crocodiles to be treated in a respectful way, based on strong, internalized beliefs – are respected, encouraging a peaceful co-existence with crocodiles. Meanwhile, stakeholders in Nikki and Sakabansi frame crocodiles as highly problematic because of their negative effects on local livelihoods and people's tranquillity (Chapter 3). Thus, they have discursively and collectively reconstructed particular informal institutions allowing them to kill crocodiles, unlike stakeholders in Fombawi who – although living with the highest number of crocodiles but experiencing the lowest damage per crocodile – collectively construct informal rules and practices that support living with crocodiles. This sustains their beliefs and culture and permits them to benefit from the advantages of crocodiles' presence in the dam.

Nikki Council members have been blamed by the daily users and the CoGes for not taking its responsibility for appropriate dam management. Non-compliance with informal rules maintains tensions among users (herders and crop farmers), with the council (vegetable producers and the council; fishermen and the council), and with users like the farmers, who continue their illegal farming activities within a radius of 1000 m of the water's edge.

6.2.3 Behaviours and observable consequences

The terrain of behaviours (the upper right quadrant) sheds light on how APD stakeholders' behaviours (expressed in their daily practices) upset the APD ecosystem services and functions, including their consequences. The focus is on observable human–crocodile interactions, dry season vegetable production, water quality, and fish biodiversity and biomass (Chapter 5).

Fishermen agree that crocodiles prey mainly on marketable fish species. In addition, it was observed that crocodiles damage fishing equipment, attack dogs, sheep, and goats, injure daily users, and dig holes in the dykes. In Nikki, the fewer than 20 crocodiles behave most

aggressively, whereas in Fombawi – with more than 300 crocodiles – the amount of damage per crocodile is lowest. In Nikki and Sakabansi, stakeholders seek solutions by changing the ecological environment, requiring others (the council, fishermen, and crocodiles) to change their behaviour, whereas in Fombawi stakeholders seek to adapt their own behaviour by respecting crocodiles and applying traditional and practical rules for sharing the dam with them. Whatever the picture, because of the permanence of the water and the presence of fish, the APDs will always attract crocodiles; so, living with crocodiles is part of the agro-ecosystem of an APD.

Recognized as contributing to improved livelihoods around APDs, dry season vegetable production upstream in the Nikki and Sakabansi APDs involves men and women (Chapters 2 and 4). However, the vegetable production system in Nikki is not environmentally friendly, because of the application of cotton pesticides and mineral fertilizers. Also, the upstream location of the gardens entails water pollution, erosion, and siltation (Chapter 5). Technical, institutional, and socio-economic constraints that affect vegetable production in the three APDs hamper the prosperity of the activity. These constraints are various, but of diminishing importance including: access to water; vegetable and seedling destruction by livestock; pest and disease management; access to markets, land, and credit; lack of equipment, seeds, fertilizers, and pesticides; problems with crocodiles; and theft of vegetables. Similar studies for crop and cotton farming are needed to appreciate cropping systems and their effects on APDs.

All APD stakeholders complained about poor APD water quality (Chapter 2). This is partially confirmed by findings of high concentrations of nitrite, nitrate, iron, and chemical oxygen demand (COD) in APDs (Chapter 5) by World Health Organization standards. Nitrate and nitrite, mainly the result of agricultural runoff, dump runoff, and human and animal wastes, may be responsible for eutrophication, resulting in the invasion of the APDs by aquatic plants. The high records of iron in the three APDs' water emanating from the ferralitic Nikki District soils are probably caused by poor watershed management: erosion, siltation, felling of trees, firewood collection.

Furthermore, APDs are subject to microbiological contaminations caused by humans and livestock through the deposit of faeces in/around the APDs and in the watersheds and through the effluent from villages that ends up in the APDs. This makes APD water unsuitable for human and livestock use (Chapter 5).

The council relies on taxation from fishing organized in APDs in Nikki District for income for local development (Chapter 2). Fishermen complain about a decrease in fish yield

that could originate from siltation, longer drought periods, water pollution, and the presence of crocodiles (Chapter 2). Chapter 5 elucidates how the APDs' fish diversity of 20 species is very low in comparison to rivers in the same watershed. In the same vein, the observed fishing selectivity, focusing on four large and marketable fish species (*Clarias anguillaris, Clarias gariepinus, Oreochromis niloticus,* and Tilapia mariae), coupled with the alleged crocodile predation more on these species than on small size fish, could have militated in favour of the low biodiversity and fish biomass in the APDs.

6.2.4 Formal rules relating to dam use and management

In relation to the terrain of systems (the lower right quadrant), two systems are addressed: the APD agro-ecosystem and the system of formal institutions relating to dam management.

The Nikki, Sakabansi, and Fombawi APDs are fed by temporary rivers that are part of the Niger River watershed. The APD ecosystem includes: (i) water originating from the rivers and drained into the dam basins during the rainy season and the surrounding watersheds (mainly dry areas), (ii) human settlements and fertile agricultural areas from where nutrients, pesticides, and pathogens are transferred through runoff into rivers and APDs – which behave like a sink during the dry season – affecting physical, chemical, and microbial water quality (Chapter 5). The dams' eco-health thus also depends on the practices in the larger watershed ecosystem (agriculture, forestry, rivers, and settlements). To manage the APD ecosystem, formal institutions set at national level should guide users' behaviours. These rules include: governance of water pollution, agricultural and pastoral activities, and wildlife management that classifies crocodiles as a protected species that should not be hunted. It is Nikki Council's duty – representing the local government since decentralization reforms that started in 2005 – to obtain financial resources for local development. The council has targeted APDs as a source of income. In return, the legitimate responsibility of the council is to maintain APDs by protecting the dam ecosystem services by monitoring all the activities and practices taking place around the dams and by mediating conflicts (Chapter 2). Existing formal rules are, however, framed differently and in many cases disregarded, because the council does not sanction those who ignore the rules. Instead, the council focuses on daily fishing in Nikki dams and taxation of herders. The lack of overall management has resulted in a lack of respect for the regulations and the failure of Nikki Council and the DGR to maintain the dams.

In short, many conflicts and tensions exist in relation to APD use and management, with consequences for the interaction between humans and crocodiles, the quality of the water, and fish diversity and biomass, caused by the neglect of formal and informal rules that should support appropriate use and the construction of informal rules that support and justify existing behaviours. As a result, food security, income generation, and livelihood quality – prime objectives of the Benin government – are affected.

6.3 Discussion

In this section, the findings of the study are linked and discussed from an ecological, a socio-cultural, and an institutional perspective, respectively.

6.3.1 Ecological perspective

From an ecological perspective, issues of biodiversity, including threats and opportunities are highlighted.

- Agricultural intensification versus biodiversity conservation in APDs

The APD ecosystems provide fundamental services to their users: provisioning, regulating, supporting, and cultural (Chapter 5). The provision of food (crops, dry season vegetables, livestock, and fish) – a primary function of agriculture – is an APD service on which the government of Benin relies to contribute to food security and local communities' livelihoods. At the same time, the APDs provide ecological conditions for water-based species like birds, snakes, monitor lizards, turtles, and crocodiles (Chapter 2). Chapter 5 substantiates how problematic APD water quality is for drinking water for humans and livestock when it comes to its physical, chemical, and microbiological composition. The question is how agricultural activities in the APD ecosystem can be intensified without losing other ecosystem services; for example, the provision of clean drinking water for livestock and humans without jeopardizing agricultural production itself. Two answers to these questions are found in the literature. The *Land Sparing* paradigm suggests that, by increasing the productivity of agricultural systems, the demand to convert unfarmed areas into productive ones will decrease, leaving more space to conserve wildlife (Green et al., 2005; Balmford et al., 2005). However, agricultural intensification disrupts many of the regulating and supporting

ecosystem services (ES), including nutrient cycling, climate regulation, regulation of water quality and quantity, pollination services, and pest control, and also alters the biological diversity basis of ES (Power, 2010; Ray and Hill, 2013). Agricultural intensification thus implies high ecological, social, cultural, public health, and economic costs (Perfecto and Vandermeer, 2008).

The *Biodiversity Friendly Farming* paradigm recognizes that agricultural intensification has deep impacts on both biodiversity and ecosystem properties. This paradigm suggests that non-intensive farming practices maintain the ecological balance and still may produce large quantities of high quality food (contributing to food security) (Phalan et al., 2011). I argue that *Biodiversity Friendly Farming* is plausible in the APDs in such a way as to optimize the management of diverse activities and serve both food production and nature conservation. Thus, shifting to a more organic production of cotton, crops, and vegetables may minimize the negative effects of mineral fertilizers and pesticides on APD water quality, as also on humans, livestock, fish, crocodiles, and other wild animals taking advantage of the APDs, and still provide high quality food and cotton. By maintaining the same crop, the eco-friendly cropping system will reduce the impact of agriculture on biodiversity and maintain the natural habitat/ecosystem functions and services of APDs.

- Fish biodiversity and fishing selectivity

Nikki Council's need to generate income from the APDs may have led to daily fishing in Nikki and fish selectivity in all the APDs. Multispecies fishery models have shown that selectivity in fishing may reduce total yield (Pope, 1991), and that targeting a limited range of species or sizes will not maximize diversity (Rochet et al., 2011). In size-based models, depletion of particular sizes by fishing affects smaller-size species because their predation is reduced, and affects larger-size species by both reducing food for predators of the harvested sizes and faster growth rates of the survivors of the selective fishing. This causes destabilizing fluctuations in biomass that are wider when the size range fished is narrower and/or the sizes fished are large (Rochet and Benoit, 2012). With fishing spread over more species and sizes, yields are higher, and impacts of fishing, such as local extinctions and biomass depletion, are lower (Gracia et al., 2012).

- Crocodiles in the APD ecosystem

Among the wild animals occupying the dams, crocodiles are the most impressive, both in number and in size (Chapter 2). Crocodiles are *keystone* species that fulfil an important role

within freshwater ecosystems by creating and maintaining deep ponds during dry periods (Mazzotti et al., 2008; Ashton, 2010). Stakeholders in Nikki District collectively agree on this ecological role of crocodiles and make use of the fact that the APDs invaded by crocodiles have water all year long (Chapter 2). In this line of thinking, the invasion of APDs by crocodiles is beneficial to the dam ecosystems that are fed by the temporary rivers (Chapter 4). Fishermen blame crocodiles for the decrease in fish yields in APDs (Kpéra et al., 2012; Kpéra et al., 2014). McNeely and Sochaczewski (1988), however, argue that the presence of crocodiles in a river increases the yield of fish, because crocodiles eat ailing fish in a significantly higher proportion than healthy fish, and this helps to improve the common health of the fish stock. In addition, crocodile droppings are nutritious for fish as these contain critically important nutrients (van der Ploeg et al., 2011a). This may also militate in favour of the high biomass of fish recorded in the Fombawi APD, as compared to Nikki and Sakabansi. Being part of the agro-ecosystem, crocodiles thus may contribute to the regulation of fish stocks and to the deepening of the dams. The negative side of the presence of crocodiles include the damage they cause to humans, livestock, and dam infrastructure.

- Water quality

Top predators such as crocodiles often reflect ecosystem degradation. Thus, the presence of crocodiles gives insights into ecosystem health (Ferreira and Pienaar, 2011). Furthermore, the deterioration of both water quality and quantity is one of the most critical causes of crocodile population declines or suppression (Ashton, 2010; Ferreira and Pienaar, 2011). This research could not monitor pesticides in APD water.). Even though this research could not monitor pesticides in APD water, the three APDs have similar water quality problems, but this does not prove that water quality is causing harm to crocodiles as they prosper in Sakabansi and Fombawi. Probably in Nikki, crocodiles are affected by the daily fishing frequency and poaching.

6.3.2 Socio-cultural perspective

In conversations, people co-construct social realities on the basis of their background and their goals, resulting in specific frames and framings. All local communities around the three APDs in Nikki District frame crocodiles as a ‘problem’ for various reasons. However, whereas in Nikki and Sakabansi crocodiles are perceived as aggressive, in Fombawi, as

people comply with the local belief that does not allow crocodiles to be treated badly, they are differently framed, and this makes the villagers interact differently with crocodiles as well.

Research devoted to solving human–wildlife conflict has focused mainly on managing wildlife (Smith et al., 2000a; 2000b). There is, however, an increasing recognition that solutions focused on wildlife alone limit managers' ability to effectively resolve conflicts. This research supports the idea that the way people interact with crocodiles has a serious impact on both perceptions of crocodiles and their behaviours. Similar beliefs and traditions relating to crocodiles as found in Fombawi are found in the Philippines (van der Ploeg et al., 2011a; 2011b; van der Ploeg, 2012) and in Burkina Faso (Lamarque et al., 2009), where crocodiles are regarded as the embodiment of ancestors and are associated with mystic powers that enable people to share a landscape with such a potentially apex carnivore. This provides a compelling argument for strategies to scale up peaceful living with crocodiles in other APDs. The researchers organized stakeholder meetings with users of the three APDs to find solutions to the problems presented by the stakeholders and also to establish how they collectively constructed the issues relating to human–crocodile interaction. After the Fombawi stakeholders were invited to talk about crocodile ecology, behaviour, and role in the ecosystem of the dams, the other stakeholders present at the meetings started to recognize other framings of crocodiles making use of the dams. The discussions among the different stakeholders from the different villages seemed to support the 'unfreezing' of existing frames, paving the way to construct new frames that opened new ways for peacefully coping with crocodiles. Changing conversations implies changing perceived realities as well as changing practices (Ford, 1999; Bate, 2005). More generally, it is argued that the evaluation of local people's tolerance thresholds and attitudes towards wildlife results in additional insights that can have significant implications for conservation (Manfredo and Dayer, 2004; Rauschmayer and Wittmer, 2007; Romanach et al., 2007).

Another socio-cultural issue arising from APD use and management is the recurrent conflict between farmers and herders. APDs are areas where fresh grass and water are available all year long. Conflicts arise when (i) herders' livestock, mainly cattle, destroy farmers' crops and (ii) transhumance corridors are closed by farmers, thus preventing herders from accessing the dams (Chapter 2). In southern Benin, the same conflicts have occurred in the lowlands and have even been bloody (Totin, 2014). Although the herders' union (UCOPER: *Union Communale des Producteurs et Eleveurs de Ruminants*) has a remit to assist in conflict resolution, farmer–herder conflicts remain intractable and have become a

political issue in Benin. The same conflicts but on different scales have occurred in Africa over the centuries (Moritz, 2010).

6.3.3 Institutional perspective

Formal, national level institutions to manage APD ecosystems should guide users' behaviours. This poses the problem of relaying the relevant information – a task which is the responsibility of Nikki Council. In terms of the protection and management of water quantity and quality, the responsibility of the councils in Benin includes forests, soils, wildlife, water resources, and ground water. Moreover, the Benin councils are supposed to ensure the preservation of the hygiene and the salubrity for their locality.

Informal rules relating to APD use and management – negotiated between the council and the users of the dams' ecosystem services to guide stakeholders in their use and management – as well as formal rules relating to the protection of crocodiles are well known by the users, but are disregarded because the council does not sanction those who ignore the formal and informal rules for managing the dams. All in all, there is a lack of overall evidence-based management, no respect of the regulations, and a failure to maintain dams by Nikki Council, which expends its efforts on overfishing in Nikki dam and taxing herders. Users' behaviour towards the informal and formal rules is imputed to the lack of communication between the council and the other stakeholders. Consequently, the dam ecosystem services are affected. When people construct different informal rules in different contexts to justify their behaviours, it makes it more difficult for change to happen (Arts and Buizer, 2009). This also shows that stakeholders in the APDs want changes, but do not seem capable of jointly acting. What is holding back this integration/optimization of the APD ecosystem services are the institutional constraints.

6.4 Implications of the research for policy and practice

6.4.1 Technical measures to improve the sustainability of agro-pastoral dams

From the discussion of the results of this thesis, several technical measures to improve the sustainability of agro-pastoral dams can be identified:

- Use of bio-pesticides

An environmentally friendly and healthy solution for vegetable producers against pests and diseases may be the use of bio-pesticides like neem products. Additionally, people can take advantage of other beneficial effects of neem products, such as the treatment of human diseases, including malaria (Koul and Wahab, 2004). To solve the current problem of provision of neem products, the farmer-based organizations (FBOs), the NGOs in the agricultural sector, and Nikki Council should encourage local production and may also advocate with the Ministry of Agriculture, Livestock Production, and Fisheries (MAEP) to subsidize neem products and make them available as they do with artificial fertilizers and pesticides.

- Soil analysis for application of artificial fertilizers

Farmers cropping around APDs should utilize soil analysis to assess whether there is a need to apply artificial fertilizers. This practice has the advantage of maintaining soil fertility and avoiding wrong and excess application. It contributes to soil health, to sustainable crop production, and to attaining targeted yield, and it will steer farmers towards the economic use of costly mineral fertilizer (Katharine et al., 2013). This work can be done by NGOs and by programmes such as the Organization for the Promotion of Organic Agriculture in Benin (OBEPAB: *Organisation Béninoise pour la Promotion de l'Agriculture Biologique*) and the Framework Programme in Support of Agricultural Diversification (ProCAD: *Programme Cadre d'Appui à la Diversification Agricole*).

- Monitoring fish biodiversity

The selectivity of fishing that focuses on large and marketable fish species (*Cichlidae* and *Clariidae*) could affect fish biodiversity and fish yield in the APDs. Moreover, the daily-based fishing in Nikki APD and the yearly fishing in Sakabansi and Fombawi may also have affected fish biodiversity and yield. Therefore, Nikki Council should monitor fish biodiversity, the selectivity of fishing, and fishing yield for a long period to adjust fishing frequency, to maintain productivity, and to prevent adverse ecological effects in the APDs.

Furthermore, as no norms are available for fish biodiversity and biomass, long term research is required in the watershed to learn about the variations in fish diversity and fish biomass and the causes these variations.

- Monitoring water quality

Although crop and cotton farming systems around the APDs were not studied in detail, it can be assumed that these create similar problems to those of the vegetable producers. This, added to the current APD water quality which is a risk to people's health and to the dam ecosystem, suggests the need to continuously monitor APD water quality (physical, chemical, microbiological composition) and the pesticide content in water, sediments, fish, and even crocodiles. As water quality assessment is costly, water quality assessment-based endogenous knowledge (Raymond et al., 2012) in APDs may assist the users and the council in monitoring the pollution trend. Nevertheless, to solve these water quality problems, watershed management is required. Also, there is a need for more fundamental research to gain knowledge about effects of agricultural practices, waste management, and agroforestry.

- Implementing agroforestry in the watersheds

The current agricultural practices around APDs reflect what is happening in their watersheds. There is a great need to shift to more environmentally friendly agricultural production in the watersheds of the APDs by implementing agroforestry farming practices under the control of the communal centre for agriculture promotion (*CeCPA: Centre Communal de Promotion Agricole*) and the council. By interspersing agricultural crops with trees, agroforestry increases productivity and provides additional income to farmers. It also has the potential to slow down runoff and trap sediment, thereby reducing erosion, siltation, and water pollution. Also, trees have the advantage of providing habitat for wildlife, thus promoting the biodiversity and aesthetic value of the watersheds. Finally, women can also benefit from the tree branches for firewood for cooking, thus reducing deforestation at the APDs' edges.

- Control of effluent/runoff

Most of the effluent from towns and villages, gardening, and cropping ends up in the APDs. The council may advocate with the Agricultural Engineering Service (DGR: *Direction du Génie Rural*) in charge of the maintenance of APDs to divert effluent from APDs. Application of this management measure will greatly reduce the volume of effluent/runoff reaching the APD waterbody; reduce contaminations of the APDs and siltation, thereby improving the APD water quality.

6.4.2 Opportunities for institutional changes

Picturing the use and management of APDs as a 'wicked' problem makes it clear that technical solutions are not sufficient. A wicked problem is complex, persistent, or recurring, often hard to detect and to fix, partly because it is linked to broader social, economic, and policy issues (Conklin, 2005; Khan and Neis, 2010). Thus, to realize the above technical measures, there is a need to explore institutional solutions that fit the complex dynamics and help change both the frames and practices of stakeholders (Aarts and van Woerkum, 2002; Leeuwis and van den Ban, 2004).

- Taking the APD system as a whole

APD management can only be improved if the stakeholders take into account the APD ecosystem as a whole, including the mechanisms that shape relevant institutions, and the constraints and opportunities experienced by stakeholders to make institutional changes happen. After presentation of the results of the diagnostic study at a stakeholder meeting that gathered the key stakeholders of the three APDs in Nikki, the urgent thing is to devise a management plan for good APD governance and management, which must be agreed upon, approved, and shared by all the stakeholders involved in the APDs. Therefore, the revision of the draft management plan designed by the council with the help of the Participative Artisanal Fisheries Development Programme (PADPPA: *Programme d'Appui au Développement Participatif de la Pêche Artisanale*) (Chapter 2), or a new management plan discussed and approved by a platform of actors, and implemented, will change local communities' behaviour.

- Institutional bricolage

The formal rules for managing the APDs are differently interpreted and even ignored because they do not take into account individual users' needs and the council does not fulfil its promises; thus, the council is not able to sanction those who ignore the rules. Also, the informal rules that have been negotiated between the council, the CoGes, and users are ignored (Chapter 2). For institutional changes to take place and to be sustained, several authors have coined the concept of 'institutional bricolage', which refers to collective action in natural resource management in which people reconstruct institutions from existing norms and practices, life histories, social identities, and social relationships (Cleaver, 2002; Yémadjè

et al., 2013; van Mierlo and Totin, 2014). Through negotiations, people construct new institutions and new realities by shaping, adjusting, uttering, eliminating, and combining elements of existing institutions (van Mierlo and Totin, 2014). Thus, the APD management plan should combine and adapt current formal and informal institutions, including those relating to interaction with crocodiles, and define sanctions for those who do not comply with the agreement, whatever their status.

- Taking responsibility for APD infrastructure costs

The decentralization reform has given Nikki Council the right to manage the 20 APDs in its area. The shift from top-down development to a more bottom-up approach is certainly promising in the sense that it has paved the way for participatory approaches that recognize the role of users and institutions in water resources management (Venot and Clement, 2013). However, the management of certain water resources like APDs, because of the fragility of freshwater ecosystems and the complexity of the situation, cannot be left to the local authority alone. The council is not able to bear the costs of dam infrastructure maintenance, including monitoring siltation, water quality, fish biodiversity, and erosion. Therefore, the national government should take responsibility for the costs and ensure that effective management takes place if it wants the APDs to contribute to food security (MAEP, 2007).

- Developing a monitoring system

Nikki Council has to act on monitoring using the WHO/Benin standards. For this, it needs to have information about users and monitoring activities for water quality, fish populations, agricultural practices, economics of the diverse activities, economic valuation of the APDs, and so on. So far, the council has not started any monitoring despite the fact that in May 2013 the whole district experienced a severe drought. For a couple of weeks, this water shortage forced everyone to drink APD water and use APD water for other household uses as all the wells dried up and the potable water from the pumps could not be accessed because the water table was too low (source: CeCPA staff, the council members, and local people's testimonies). Such an experience should serve as a lesson to the council to take more initiative in relation to APD management. To improve APD ecosystem services and management, an actor platform initiated by the council could act as a space for changes in APDs.

- Developing procedures and incentives that support negotiations

The formal rules for managing and using the dams in Nikki District are not taken into account by the users because, for them, the council itself does not keep its promises. Also, the informal rules that have been negotiated among the town council, dam managers, and users are ignored and without consequences. This collective irresponsibility results from opportunistically constructing and reconstructing both formal and informal rules according to the goals people try to accomplish. Therefore, procedures and incentives that support negotiations should be developed among stakeholders, reducing uncertainty and ambiguity in the APDs' stakeholder interactions – these being prerequisites for institutional changes (Ostrom and Basurto, 2011). Also, more attention should be paid to the development of sanctions, including how these should be implemented.

- Managing waste in towns and villages

In Nikki District, local communities use the open dumping method to manage household refuse (Chapter 2), and most of the open dumpsites are arbitrarily located. Little consideration is paid to environmental impacts in the selection of the dumpsites, especially in villages. Meanwhile, agricultural runoff, effluent, and refuse dump runoff from villages during the rainy season are stored in the APDs, which act as a sink during the dry season. This results in poor APD water quality that may cause waterborne disease outbreaks and health problems, and also affect the regulating services of APD ecosystem. Therefore, the council must urgently survey the accumulation of waste in dumpsites in order to identify the best available disposal location. This location must comply with the requirements of government regulations, and at the same time must minimize economic, environmental, health, and social costs. Moreover, the council should institutionalize integrated waste management, improve awareness amongst the local communities, and encourage the use of organic fertilizers by vegetable producers and farmers.

- Implementing watershed management process

The Nikki, Sakabansi, and Fombawi APDs are under the influence of the attributes of the Oli sub-watershed, which is part of the large Niger River watershed (Chapter 5). Changes in these watersheds that originate from natural and anthropogenic factors, including changes in farming systems, overgrazing, deforestation, pollution, soil erosion, climate change, and so forth, may affect APD ecosystems also. Hence, to improve APD ecosystem functions and services, integrated watershed management based on the management of both human

activities and natural resources on a watershed basis is required. The integrated watershed management process operates by addressing the ecological, economic, and societal issues simultaneously to ensure adequate supplies of good quality water and the other ecosystem services while still preserving the hydrological, biological, and chemical ecosystem functions. This process works well when there is a supportive policy and legal framework (Darghouth et al., 2008). In Benin, a national action plan for integrated water resources management, adopted in 2011, includes all the watersheds in the country. It is designed to be implemented for 15 years (MMEE, 2011). This plan goes beyond the country limit and should also be available at the district level and be included in the district development plan (PDC: Plan de Development Communal). The appropriate implementation of this action plan may contribute to improving the APD ecosystems and watersheds all over the country. However, improvements in watershed management should be accompanied by research/monitoring so that changes in management can be verified and shared with users.

6.4.3 Setting up an innovation platform as a conducive space for improving APD ecosystem services and management

The complexity of APD management, linked to the multiple uses and the multiplicity of stakeholders, leads to the underlying recurrent and intractable conflicts that people have been experiencing. All stakeholders (daily users of the dams, herders, vegetable farmers, farmers cropping near the dams, and fishermen) want to benefit from the dams. To guarantee sustainability of the services provided by the APD ecosystems and to come up with an appropriate management scheme, a collective learning process that involves the contextual re-ordering of relations in multiple social networks is needed (Leeuwis and Aarts, 2011). Given that innovations emerge from interactions among different stakeholders (Leeuwis and van den Ban, 2004; Osei-Amponsah et al., 2014; Totin et al., 2014), frequent communicative exchanges among stakeholders are of critical significance for change. For APD sustainability, experiences from elsewhere support our suggestion about organizing repeated interactions among a relatively small number of stakeholder representatives who are able to develop institutions for monitoring and enforcing a degree of cooperation, and who are regarded as legitimate by all stakeholders (Vollan and Ostrom, 2010; Vollan, 2008; Ostrom, 2011). A stakeholder platform would be a useful vehicle for organizing collective action that can make change happen in APD use and management (Nederlof et al., 2011; Struik et al., 2014). Such platforms are often emergent institutions which can take many forms, from simple informal

'spaces' where stakeholders meet, to more organized arrangements with particular rules and functions. Regular meetings through a platform may help stakeholders involved in APDs to raise their ability to talk and think together, to share knowledge through conversation, and to enhance their collective wisdom (Isaac, 1999). It is a place for social learning that allows stakeholders to interact to solve a problem, through which they acquire new skills (both technical and social), produce knowledge, develop relationships, and share local experiences (about conflicting activities around APDs, water pollution, siltation of APDs, APD ecosystem sustainability, the role of crocodiles in a healthy ecosystem, food security, climate change, and poverty alleviation). As a result, through social mobilization, action planning, and self-evaluation, the platform will search for solutions to problems. Exchanges of knowledge – including both local and scientific knowledge – and experiences may result in the co-creation of conditions to transcend blaming and instead discuss differences and similarities among stakeholders (Pearce and Littlejohn, 1997) and develop new realities, including rules to deal with these new realities (Isaac, 1999).

6.5 Reflection on the research and input for the future research agenda

This thesis was conducted within the framework of the Convergence of Sciences Strengthening Innovation Systems (CoS-SIS) Research Programme. CoS-SIS focused on inter- and transdisciplinary research and on institutional changes that have been widely acknowledged as imperative for agricultural development (Word Bank, 2007; Struik et al., 2014). The challenge confronted in this thesis is to find a way to put this convergence into a perspective that explores various types of interactions, bringing into play conceptions and practices, strategies, actors, and contexts. The integral ecology framework has proved fruitful as it fits with the original aim of CoS-SIS: Convergence of Sciences, involving natural and social sciences, as well as formal science and local know-how or 'indigenous knowledge'. Next, the CoS-SIS research approach aimed to conduct experiments that originated from constraints identified during the diagnostic study which were clearly expressed by stakeholders as their priorities. Moreover, the programme aimed to set up an actor platform called Concertation and Innovation Group (CIG) to address institutional constraints to make change happen in APDs (www.cos-sis.org). Indeed, stakeholders involved in APDs expressed their main concerns, but the complexity faced in APD use and management has resulted in recurrent and persistent conflicts. Different knowledge gaps were revealed with the help of

the IE framework, providing arguments for a first in-depth exploration of what is going on in APDs, creating a more organized insight into the problems at stake, and identifying possible solutions before designing interventions or experiments and setting up the CIG.

This thesis started from a scoping study on the basis of which relevant research objectives were identified. Following the scoping study, a diagnostic study explored the wider socio-technical and institutional system of three case studies, including the analysis of stakeholders' framings and practices. The diagnostic study provided an in-depth study of practices carried out in the APDs and a set of relevant research questions that were studied in the four empirical chapters. The diagnostic study, however, also revealed the enormous complexity of the situation, which could not be fully studied within this thesis. Our research has also generated new concerns that require data to be collected in different and additional domains, amongst which:

- *The economic domain*

- Economic evaluation of all activities around the dams;
- Estimation of the economic benefits from the APDs;
- Economic evaluation of crocodile damage to dam infrastructures and to local communities' properties.

- *The ecological domain*

- Assessment of the seasonal variation of physical, chemical, and microbiological water parameters and identification of the origin of the pollution;
- Assessment of the seasonal variation in pesticides in APD water, sediments, fish, and crocodiles;
- Inventory of all APDs in Benin, including the status of their ecosystem services to provide the district councils with more information and assistance to exchange best practices;
- Interactions between the components of the watershed system and information on long-term trends are needed for better understanding and evidence-based management;
- Study of fish diversity and productivity upstream and downstream over many years;
- Crocodile predation on fish: species diversity and abundance and impact on fish productivity.

- *The socio-cultural and institutional domain*

- Crocodile–human behaviour; comparing human behaviour shaped by beliefs and culture versus a negative approach;
- Governance of Nikki Council: responsibilities, elected members, budgeting and controls, decision making, relationship with national ministries and government, access to data information, and so forth;
- Governance of the river watersheds;
- Developing and monitoring innovation platforms to address institutional constraints, utilize formal research results, and facilitate the occurrence of change in APDs**.**

6.6 *Final reflection for further development and recommendations*

Intensively used by local communities, livestock, and crocodiles for diverse purposes, APD ecosystem services contribute to users' livelihoods. This thesis has resulted in a sense of urgency because all the stakeholders involved experience problems relating to the use or management of the dams. Meanwhile, they interpret the problems differently, including causes and solutions, resulting in a continuation and even deterioration of the situation. It is this collective irresponsibility that contributes to water pollution, loss of fish diversity, and persistent and intractable conflicts among users themselves and with the local government. Therefore, the improvement in APD use and management should start from system thinking. This implies that a dialogue among all stakeholders should be organized on a regular basis, making people aware of their interdependence, exchanging experiences, practices, and ideas (to capitalize on existing institutional diversity as the inspiration for change and also to co-create commonly accepted solutions). Vegetable production should be based on (i) bio-pesticide application and manure, (ii) a more active role for producer associations to support their members, and (iii) exchange visits to discuss sustainable vegetable production management and district governance of the APDs. The monitoring of APD ecosystem services like water quality and fish biodiversity should guide the MAEP in collaboration with the Ministry of Mines, Energy, and Water (MMEE: *Ministère des Mines, de l'Energie et de l'Eau*) to manage the river watersheds. The monitoring of fishing frequency and selectivity should guide the council to maintain a diverse and healthy fish population. Finally, it should be realized that the availability of water and fish will always attract crocodiles to the APDs. Therefore, stakeholders should accept that living with crocodiles is part of the APD agro-

ecosystem and thus adapt their own behaviours towards crocodiles in order to peacefully share APD ecosystem services with them.

This is the first thesis to report on the eco-sociological status of APDs in northern Benin. More research is required over longer timeframes and the larger watershed to understand the mechanisms that cause ecological deterioration, competition for ecosystem services, and poor governance. This study has made clear that future APD management in Benin should be based on evidence-based information and constructive dialogue with users.

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Summaries in English and French

Summary

Like several other African countries, the Republic of Benin has been developing an ambitious water policy framework, including an action plan with a focus on Integrated Water Resources Management (IWRM). Agro-pastoral dams (APDs) – water reservoirs constructed to provide water for livestock and for agricultural development – have been constructed all over Benin. These APDs face several conflicts rooted in the multi-functionality of APDs and with this the involvement of different stakeholders, including crocodiles that share APD ecosystem services and influence the management of dams. This thesis aims to understand the multi-functional and multi-stakeholder use and management of APD ecosystem services in Benin. A related aim is to find opportunities for a more optimal and peaceful use and management of APD ecosystem services. The research was conducted as part of the broader Convergence of Sciences – Strengthening Agricultural Innovation Systems (CoS-SIS) Research Programme (www.cos-sis.org) that applied multi- and transdisciplinary approaches to address social and technical challenges in agriculture and natural resource management.

Chapter 1 sketches the general background to the study. It starts with an explanation of the relevance of water reservoirs in Africa, followed by the importance of APDs for the Government of Benin, which has targeted them to improve food security and induce intensification of the agricultural sector. Next, Chapter 1 introduces the integral ecology (IE) framework as the conceptual inspiration for the study. The IE framework provides a comprehensive and inclusive research perspective that can accommodate different disciplinary orientations and methodologies. It thus helps to develop an integral understanding that takes into account institutional, technical, socio-economic, and environmental dimensions of problem situations. Chapter 1 concludes with the choice of a case study approach as an overarching research design and the selection of the Nikki, Sakabansi, and Fombawi as case study areas.

Chapter 2 provides the diagnostic entry point of this thesis. The chapter identifies stakeholders involved in APD use and management in the three cases, as well as the institutional and technical impediments and opportunities for managing the APDs as perceived by the stakeholders. It describes the multiple functions that APDs provide, such as: drinking water supply for humans, livestock watering place, fish farming, vegetable production, food cropping, cotton farming, cleaning, washing, swimming, cooking, small business water use, and house and road construction. The involvement of human and non-human stakeholders (crocodiles and livestock) makes an APD a complex system, impeding

agreement on common rules for their management. Instead, the dams have become the scene of competitive claims, resulting in multiple and persistent conflicts and disagreements among stakeholders (farmers versus herders, Nikki Council versus vegetable producers, fishermen versus Nikki Council, fishermen and other APD users versus crocodiles, and so forth). This diagnostic study argues that all stakeholders tend to look at themselves as victims and blame others for violating rules and the sub-optimal use of the APDs. It also shows that existing institutions for managing APDs are differently interpreted and mostly ignored. Chapter 2 concludes by indicating domains for future research to be empirically studied (Chapters 3–5).

With the aim of supporting living peacefully with crocodiles, **Chapter 3** provides an understanding of the way stakeholders frame the presence of crocodile, including the formal and informal institutions they apply to cope with crocodiles. Because of the fear that crocodiles engender and crocodiles' negative effects on local livelihoods and people's tranquillity, all stakeholders frame the presence of crocodiles as problematic. Although incidents with crocodiles are highest in number in Fombawi (with more than 300 crocodiles), the relative amount of damage per crocodile is lowest there. This may suggest that the crocodiles in Fombawi are less aggressive than those in Nikki and Sakabansi, and/or that the Fombawi inhabitants are more tolerant towards crocodiles because of the embedding of their specific beliefs and cultural realities relating to crocodiles. In Nikki and Sakabansi, stakeholders construct particular informal institutions that allow them to deny formal rules (national and international regulations and laws that consider crocodiles as a protected species) and thus to kill them. In Fombawi, crocodiles are protected by the collective belief that they are holy creatures and thus should not be killed. From this belief, stakeholders in Fombawi have constructed informal rules and socially embedded practices that assist them to live in peace with crocodiles. Chapter 3 suggests that these rules are constructed via intensive communication among stakeholders exchanging experiences and ideas, resulting in a peaceful human–crocodile relationship.

Vegetable production has been identified by the Government of Benin as one of the ways to improve food security in the region. **Chapter 4** examines dry season vegetable production systems around the APDs and identifies constraints that hinder related activities. The traditional vegetables grown include *Amaranthus cruentus*, *Sesamum indicum*, *Abelmoschus esculentus*, *Capsicum frutenscens*, *Corchorus olitorus*, *Lycopersicon esculentum*, *Hibiscus sabdariffa*, and *Solanum macrocarpon*; and the exotic vegetables consist mainly of *Lactuca sativa* and *Brassica oleracea*. In Nikki, a significant difference exists between men and women when it comes to plot size and also to soil fertility

management practices. In Nikki, the men's cropping system is characterized by large plots, more exotic and marketed vegetables (lettuce, tomato, and cabbage), more use of mineral fertilizers and cotton pesticides, and crop rotation. Constraints affecting vegetable production include: access to water; vegetable and seedling destruction by livestock; pest and disease management; access to markets, land, and credit; lack of equipment, seeds, fertilizers, and pesticides; problems with crocodiles; and theft of vegetables. These vegetable cropping systems around APDs as well as the specific location of Nikki and Sakabansi are perceived by Nikki Council – which is in charge of APD management – as major causes of siltation, erosion, and water pollution. Therefore, the council wishes to relocate the vegetable plots in Nikki and Sakabansi from upstream to a downstream site, and this causes tensions between Nikki Council and the vegetable producers. The chapter ends with the suggestions to change to more organic agricultural practices (using bio-pesticides and organic manure), to realize a more active role for producer associations that support their members, and to organize an exchange visit to Kalalé District by members of the associations and the council with the aim of discussing sustainable vegetable production management and district governance of the APDs.

Given the different complaints about water pollution, **Chapter 5** assesses the health status of the APD ecosystem, with water quality (physical, chemical, and microbiological composition), fish diversity, and fish biomass as indicators. This study shows that dam water quality is problematic because of significantly high levels of nitrite, nitrate, iron, and chemical oxygen demand (COD). This pollution – probably the result of agricultural runoff, dump runoff, and human and animal wastes – may be responsible for the invasion of aquatic plants in the APDs resulting from eutrophication reducing water quality and altering the ecological structure and function of APDs. Moreover, the study substantiates the contamination of APD water with harmful bacteria (Coliforms, *Enterococcus faecalis*, *Escherichia coli*, spore of *Clostridium*, *Salmonella typhi*, *Salmonella typhimurium*, *Salmonella enteritidis*, and *Campylobacter jejuni*) detrimental for both human and livestock water consumption. Additionally, 20 fish species are spread in the three APDs, of which four large-size species (*Clarias anguillaris, Clarias gariepinus, Oreochromis niloticus,* and *Tilapia mariae)* – associated with a market value – are targeted for fishing. Although Fombawi dam is home to more crocodiles, its fish biomass is higher than that in Sakabansi and Nikki. The chapter ends by recommending APD management strategies that contribute to the restoration of APD agro-ecosystem services by means of an appropriate application of fertilizers and pesticides,

reforestation of the APD watershed, and prevention of agricultural and urban runoff and erosion. Such requires the collaboration of all stakeholders, including Nikki Council.

Using the IE framework, **Chapter 6** presents the synopsis of the main findings. The results of the empirical studies are integrated from an ecological perspective, a socio-cultural perspective, and an institutional perspective. The ecological perspective discusses how plausible the agricultural intensification in APDs – to meet the Benin Government's needs – is for conserving biodiversity. Furthermore, the importance of maintaining fish biodiversity by spreading fishing activities over more fish species and sizes is discussed. As part of the APD agro-ecosystem, crocodiles play an ecological role in contributing to the regulation of fish stocks and to the deepening of the dams, and by giving insights into ecosystem health. From the socio-cultural perspective, it is argued that the way people interact with crocodiles has a serious impact both on perceptions of crocodiles and on their behaviours. Exchanging experiences and practices for a more peaceful relationship with crocodiles, as happens in Fombawi, would contribute to sustainable APD management. From an institutional perspective, APD users' non-compliance with the informal rules was imputed to the lack of communication between the council and other stakeholders. The implications of the research for policy and practice should be intensively discussed with all stakeholders involved, including Nikki Council. Promising technical measures to improve the sustainability of APDs should be discussed, including the use of bio-pesticides, soil analysis for the appropriate application of artificial fertilizers, monitoring fish biodiversity and water quality, and implementing agroforestry in the watersheds.

To realize these technical measures, institutional solutions that help change both stakeholders' frames and their practices are also required and are of utmost importance: consider the APD system as an interacting whole, act collectively, develop a collective monitoring system, manage waste in towns and villages, government should accept responsibility for APD infrastructure costs, develop incentives that support negotiations, and define sanctions for those who do not respect rules, and implementing watershed management process. It is pointed out that improvements in watershed management should be accompanied by research/monitoring so that changes in management can be verified and shared with users. It is also suggested that an innovation platform be established in which all stakeholders can participate to discuss changes that should be collectively developed and realized, resulting in optimal APD ecosystem services and management.

Finally, a follow-up research agenda is suggested in three domains:

- *Economic domain* (economic evaluation of all activities around the dams; estimation of the economic benefits from the APDs; economic evaluation of crocodile damage to dam infrastructures and to local communities' property);
- *Ecological domain* (assessment of the seasonal variation in physical, chemical, and microbiological water parameters, and of pesticides in APD water, sediments, fish, and crocodiles; inventory of all APDs in Benin and their ecosystem service status; fish diversity and productivity and water quality upstream and downstream over many years; crocodile predation on fish species);
- *Socio-cultural and institutional domain* (crocodile behaviour; human–crocodile interaction; governance of Nikki Council; governance of the river watersheds; developing and monitoring innovation platforms).

The thesis ends by summarizing an integrated set of recommendations:

- Improvements in APD use and management should start from system thinking;
- Vegetable production should be based on more organic production methods and executed downstream;
- Water quality and fish biodiversity should be intensively monitored and adjusted if needed;
- Living with crocodiles should be considered part of the APD agro-ecosystem, and people should thus adapt their behaviours towards crocodiles in order to peacefully share APD ecosystem services with them.

Résumé

Comme la plupart des pays africains, le Bénin dispose d'un code de l'eau axé sur la Gestion Intégrée des Ressources en Eau (GIRE). Construites à travers tout le Bénin, les retenues d'hydraulique pastorale ou retenues d'eau servent à l'abreuvement du bétail et au développement agricole. A cause de leur multiple fonction, ces retenues sont aujourd'hui confrontées à divers conflits dus à l'implication dans leur gestion de plusieurs parties prenantes dont les crocodiles, qui bénéficient aussi des services fournis par l'écosystème des retenues d'eau. Cette thèse vise à comprendre la multifonctionnalité, l'utilisation, l'aménagement et la gestion par plusieurs parties prenantes des biens et services écosystémiques des retenues d'eau au Bénin. Un objectif connexe est de trouver des opportunités pour une utilisation et une gestion plus optimale et pacifique des biens et services écosystémiques des retenues d'eau. Cette recherche entre dans le cadre du Programme Convergence des Sciences – Pour le renforcement des systèmes d'innovation agricole (CoS-SIS) (www.cos-sis.org) – axé sur des approches pluri- et transdisciplinaires pour relever les défis sociaux et techniques que font face l'agriculture et la gestion des ressources naturelles.

Esquissant le contexte global de l'étude, le **Chapitre 1** a démarré par la pertinence des retenues d'eau en Afrique, suivi de leur importance pour le gouvernement du Benin qui les a ciblées comme un moteur de développement pour induire l'intensification du secteur agricole et contribuer à la sécurité alimentaire. Ensuite, le chapitre 1 a abordé le cadre conceptuel de la thèse qu'est la théorie de l'Ecologie Intégrale, une perspective de recherche globale et inclusive impliquant plusieurs disciplines et différentes méthodologies de recherche. Ainsi, l'Ecologie Intégrale concourt à développer une compréhension totale prenant en compte les dimensions institutionnelle, technique, socio-économique et environnementale des problèmes rencontrés. Finalement, le Chapitre 1 aborde l'étude de cas comme une approche de la recherche globale et la sélection des retenues d'eau de Nikki, Sakabansi et Fombawi comme les cas à étudier.

Point d'entrée de cette thèse, le **Chapitre 2** est une étude diagnostique qui identifie les parties prenantes impliquées dans l'utilisation, l'aménagement et la gestion des trois retenues d'eau, ainsi que les contraintes institutionnelles et techniques et les opportunités existantes de gestion de ces retenues telles que perçues par les parties prenantes. L'étude diagnostique décrit les multiples fonctions des retenues que sont l'approvisionnement en eau potable aux populations locales, l'abreuvement du bétail, la pisciculture, le maraîchage, les aires de

cultures vivrières et de coton, la natation, les utilisations pour un but domestique et pour les petites activités commerciales et enfin pour la construction des bâtiments et des routes. L'implication des populations locales, des crocodiles et du bétail dans l'utilisation et la gestion des retenues d'eau assimile, ces retenues à des systèmes complexes, entravant le respect des règles qui régissent leur fonctionnement et leur gestion. Ainsi, les retenues sont devenus la scène de constantes revendications, résultant en de multiples et persistants conflits et désaccords entre les parties prenantes (agriculteurs – éleveurs ; Mairie de Nikki – Maraîchers ; pêcheurs - Mairie de Nikki ; pêcheurs - utilisateurs des retenues par rapport aux crocodiles, etc.). De cette étude diagnostique, il ressort que tous les intervenants ont tendance à se présenter comme des victimes et à blâmer les autres pour la violation des règles et l'utilisation anarchique des retenues. Aussi, les institutions visant la gestion des retenues sont diversement interprétées et surtout méprisées par les parties prenantes. Le Chapitre 2 conclut en indiquant les axes de recherche future (Chapitres 3-5).

Avec pour ambitionnant la cohabitation pacifique avec les crocodiles, **le Chapitre 3** fournit une compréhension sur la manière dont les parties prenantes interprètent la présence des crocodiles, y compris les institutions formelles et informelles relatives aux crocodiles. En raison de la crainte qu'engendrent les crocodiles et de leurs effets négatifs sur les biens et la tranquillité des populations locales, la présence des crocodiles dans les retenues est perçue comme étant très problématique. Bien que le nombre absolu de dégâts causés par les crocodiles soit plus élevé à Fombawi (abritant 300 crocodiles), le nombre relatif de dégâts par crocodile y est plus faible. Cela laisse comprendre que les crocodiles de Fombawi sont moins agressifs que ceux de Nikki et de Sakabansi, et/ou les habitants de Fombawi tolèrent mieux la présence des crocodiles en raison des croyances qui entourent les crocodiles. A Nikki et à Sakabansi, les populations construisent de nouvelles règles informelles leur permettant d'ignorer les règles formelles (lois qui considèrent les crocodiles comme des espèces protégées aux niveaux national et international) donc de braconner les crocodiles. A Fombawi, les crocodiles sont protégés par une croyance collective qui les considère comme des créatures sacrées et qui ne tolère pas qu'on les tue. De cette croyance, les populations de Fombawi ont construit des règles informelles et des pratiques socialement intégrées à leur culture qui facilitent la cohabitation pacifique avec les crocodiles. Le Chapitre 3 montre que ces règles sont entretenues par une communication intensive entre les populations se partageant leurs expériences et idées, conduisant à une relation pacifique entre les hommes et les crocodiles.

La culture maraîchère a été identifiée par le gouvernement du Bénin comme l'un des moyens pour améliorer la sécurité alimentaire. Le **Chapitre 4** examine les systèmes de production des légumes autour des retenues d'eau en saison sèche et identifie les contraintes qui entravent le maraîchage. Les légumes cultivés sont *Amaranthus cruentus*, *Sesamum indicum*, *Abelmoschus esculentus*, *frutenscens Capsicum*, *Corchorus olitorus*, *Lycopersicon esculentum*, *Hibiscus sabdariffa*, *Solanum macrocarpon*, *Lactuca sativa* et *Brassica oleracea*. A Nikki, une différence significative existe entre hommes et femmes en ce qui concerne la taille des exploitations et la gestion de la fertilité des sols. A Nikki, le système de culture des hommes se caractérise par l'emblavure de grandes superficies, la culture des légumes exotiques destinés à la vente (laitue, tomate et chou), l'utilisation d'engrais minéraux et de pesticides de coton et la pratique de la rotation des cultures. Au nombre des contraintes de la culture maraîchère figurent l'accès à l'eau, la destruction des pépinières par le bétail, la gestion des ravageurs et des maladies, l'accès aux marchés, à la terre et au crédit, le manque d'équipements, de semences, d'engrais et de pesticides, les problèmes avec les crocodiles et le vol des légumes. A cause de ces divers systèmes de culture autour des retenues et de la position (en mont) des parcelles de cultures maraîchères á Nikki et á Sakabansi, la Mairie de Nikki - chargée de la gestion des retenues d'eau – accusent les producteurs d'être les principales causes de l'ensablement des retenues, l'érosion des sols et la pollution de l'eau des retenues. Par conséquent, å Nikki et å Sakabansi la Mairie envisage déplacer les parcelles de cultures maraîchères de l'amont vers un site en aval, ce qui provoque des tensions entre la Mairie et les producteurs. Enfin, le chapitre 4 suggère des pratiques agricoles plus respectueuses de l'environnement (utilisation des bio-pesticides et des engrais organiques) et l'organisation d'une visite d'échange à Kalalé par les membres des associations de cultures maraîchères et la Mairie de Nikki dans le but d'échanger sur les questions liées à la gestion durable du maraîchage et de la gouvernance de la Commune de Nikki en relation avec les retenues d'eau.

Compte tenu des nombreuses plaintes relatives à la pollution de l'eau des retenues, le **Chapitre 5** évalue l'état de santé de l'écosystème des retenues, avec comme indicateur la qualité de l'eau (composition physique, chimique et microbiologique), la diversité des poissons et la biomasse des poissons. Cette étude montre que la qualité de l'eau des retenues est problématique en raison des niveaux significativement élevés de nitrite, nitrate, fer et de la forte demande chimique en oxygène (DCO). Cette pollution - probablement due au ruissellement des déchets agricoles, des ordures ménagères et des déjections humaines et animales - peut être responsable de l'invasion des plantes aquatiques dans les retenues

résultant de l'eutrophisation et qui réduit la qualité de l'eau et modifie la structure et les fonctions écologiques des retenues. De plus, l'étude démontre la contamination de l'eau des retenues par des bactéries nocives (coliformes, E*nterococcus faecalis, Escherichia coli,* spores de Clostridium, *Salmonella typhi*, *Salmonella typhimurium*, *Salmonella enteritidis* et *Campylobacter jejuni*) néfastes à la fois à la consommation humaine et à celle des animaux l'élevage. En outre, 20 espèces de poissons ont été identifiées dans les trois retenues, dont *Clarias anguillaris, Clarias gariepinus, Oreochromis niloticus*, et *Tilapia mariae,* quatre espèces de grandes tailles et å valeur marchande ciblées lors de la pêche. Malgré la forte présence des crocodiles å Fombawi, la biomasse de poissons y est plus élevée qu'å Sakabansi et å Nikki. Finalement, le chapitre recommande des stratégies de gestion des retenues qui contribuent à la restauration des services agro-écosystémiques par l'application d'engrais et des pesticides appropriés, le reboisement des berges et la prévention des retenues du ruissellement agricole et urbain. Cela exige la collaboration de toutes les parties prenantes, y compris la Mairie de Nikki.

S'appuyant sur la théorie de l'écologie intégrale, le **Chapitre 6** présente le résumé des principales conclusions de la thèse. Les résultats des chapitres empiriques ont été regroupés en trois perspectives (écologique, socio-culturelle et institutionnelle). Le point de vue écologique explique comment plausible est l'intensification agricole autour des retenues - pour répondre aux besoins du gouvernement du Bénin - et la conservation de la biodiversité. En outre, l'importance de maintenir la biodiversité des poissons en pêchant toutes espèces et de tailles de poissons est discutée. Faisant partie intégrante de l'écosystème des retenues d'eau, les crocodiles jouent un rôle écologique important en contribuant à la régulation du stock de poissons, au rejaillissement de l'eau et sont un indicateur de l'état de santé des écosystèmes aquatiques. Du point de vue socio-culturel, il ressort que la manière d'interagir avec les crocodiles a un impact à la fois sur les perceptions des populations et le comportement des crocodiles. L'échange d'expériences et de pratiques pour une cohabitation plus pacifique avec les crocodiles peut contribuer à la gestion durable retenues d'eau. Du point de vue institutionnel, le non-respect par les utilisateurs des retenues des règles informelles établies par la Mairie de Nikki, est dû à l'absence de communication entre la Maire et les autres parties prenantes. Les implications de la recherche pour les politiques et la pratique doivent être intensément discutées avec toutes les parties prenantes concernées, y compris la Mairie Nikki. Les mesures techniques envisagées d'amélioration de la durabilité des retenues doivent être discutées, y compris l'utilisation des bio-pesticides, l'analyse des

sols pour l'application appropriée des engrais chimiques, le suivi de la biodiversité des poissons et de la qualité de l'eau, et la pratique de l'agroforesterie dans les bassins versants.

Pour réaliser ces mesures techniques, des solutions institutionnelles suivantes qui peuvent contribuer à changer aussi bien les perceptions des populations et les pratiques des parties prenantes sont également nécessaires et d'une importance capitale: (1) considérer une retenue d'eau comme une entité dont les éléments interagissent entre eux ; (2) agir collectivement et développer un système de surveillance collective ; (3) gérer les déchets ménagers des villes et villages ; (4) le gouvernement doit supporter les coûts de maintenance des infrastructures d'hydraulique pastorale ; (5) développer des mesures d'incitations qui soutiennent les négociations ; (6) définir des sanctions pour ceux ne respectant pas les règles ; (7) mettre en œuvre un processus d'aménagement des bassins versants. Il est noté que les améliorations relatives à l'aménagement des bassins versants doivent être accompagnées par la recherche afin que les changements puissent être vérifiés et partagés avec les utilisateurs. Il est également suggéré qu'une plateforme d'innovation soit mise en place où toutes les parties prenantes peuvent discuter sur les changements qui devraient être collectivement développés et réalisés, afin de conduire à une utilisation optimale et à la gestion des services écosystémiques des retenues d'eau.

Enfin, un programme de recherches futures dans les trois domaines suivants est suggéré:

- Domaine économique (évaluation économique de toutes les activités menées autour des retenues d'eau; estimation des avantages économiques des retenues d'eau; évaluation économique des dégâts causés par les crocodiles aux infrastructures hydrauliques et aux biens des populations locales);

- Domaine écologique (évaluation de la variation saisonnière des paramètres physico-chimique et microbiologique et de pesticides dans l'eau, les sédiments, les poissons et crocodiles; inventaire de toutes les retenues d'hydraulique pastorale au Bénin et du statut des biens et services écosystémique; la diversité des poissons et la productivité et qualité de l'eau amont et en aval sur plusieurs années; la prédation des crocodiles sur les espèces de poissons);

- Domaine socio-culturel et institutionnel (comportement des crocodiles; interaction homme-crocodile; gouvernance de la Mairie, gouvernance des bassins versants des rivières; mise en place et suivi des plateformes d'innovation) ;

La thèse termine en résumant un ensemble intégré de recommandations comme suit:

- L'amélioration de l'utilisation et de la gestion des retenues d'hydrauliques pastorales doit être vue sous une approche holistique ;

Résumé

L'utilisation et l'amélioration de la gestion doivent commencer par une réflexion systémique;

- Les parcelles de cultures maraîchères doivent être installées en amont des retenues et le système de cultures basé sur des méthodes de production biologique ;

- La qualité de l'eau et de la biodiversité des poissons doivent être intensivement suivies et ajustées si nécessaire;

- Vivre avec les crocodiles doivent être considéré comme faisant partie intégrante de l'agroécosystème des retenues d'hydraulique pastorale et les populations doivent adapter leurs comportements à l'égard des crocodiles afin de partager avec eux et de façon pacifique les biens et services écosystémiques de ces retenues.

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Posters

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Kpéra, G.N., 2015. Animaux sacrés du Bénin ; les crocodiles et les serpents (Holy Animals of Benin: Crocodiles and Snakes). 52'. AB production, France.

Kpéra, G.N., 2008. De l'amour pour les parias : les crocodiles du Benin (Love for Outcasts: Crocodiles of Benin). 23'. AB production, France.

Curriculum vitae

Gnanki Nathalie KPERA was born on 27 July 1975 in Benin. After completing secondary education in 1997, she started agricultural studies at the University of Abomey Calavi in Benin where she graduated in 2002 with an Engineer Degree in Agronomy in Natural Resources Management (Forest, Wildlife, Water, and Fishery) with special emphasis on *the invasion of ponds by crocodile species*. Since 2003, she has been working as a research assistant at the National Institute of Agricultural Research and involved as research associate at the Laboratory of Applied Ecology, Faculty of Agronomic Sciences, University of Abomey Calavi.

In 2006, she was awarded a scholarship by the Institute of Environmental Sciences of Leiden University, The Netherlands, and acquired a certificate on Park and Wildlife Management after training in wildlife schools and study tours in Cameroon, Kenya, Tanzania, and The Netherlands. In 2008, she went back to the University of Abomey Calavi where she obtained her Diplôme d'Etudes Approfondies (DEA) (MPhil degree) in Natural Resources Management. Her DEA research focused on the *status of crocodile species and the influence of physical and chemical water parameters on crocodile species distribution in W National Park in Benin*. In 2009, Nathalie was granted a PhD fellowship by the Netherlands Universities Foundation for International Cooperation (Project NPT/BEN/146/NUFFIC) to undertake PhD research at Wageningen University in the departments of Animal Production Systems (APS) and Communication, Philosophy, and Technology (CPT). She joined the Convergence of Sciences-Strengthening Agricultural Innovation Systems (CoS-SIS) Research Programme (www.cos-sis.org), which aimed to address institutional and technical challenges for smallholder farmers in agriculture and natural resources management to ensure food security. Nathalie is now building an interdisciplinary curriculum which bridges social sciences and natural sciences to understand the *complex issue of the management of agro-pastoral dam ecosystem services caused by the involvement of human and non-human stakeholders (crocodiles and livestock) and resulting in different kinds of conflicts*.

Contact: **nathaliekpera@gmail.com**

WIAS PhD training certificate

Completed Training Activities

Education Certificate

Completed Training and Supervision Plan
***Kpéra Gnanki Nathalie* (APS/WIAS)**

The Basic Package	**Year**	**Credits**
WIAS Introduction Course	2009	1.5
Philosophy of Science and/or Ethic	2013	1.5
International conferences		
CoS-SIS workshop, Wageningen, The Netherlands	2009	1.5
CoS-SIS workshop, Cotonou, Benin	2010	1.2
CoS-SIS workshop, Bamako, Mali	2010	1.5
CoS-SIS workshop, Elmina, Ghana	2012	1.5
CoS-SIS workshop, Bamako, Mali	2010	1.5
CoS-SIS workshop, Accra, Ghana	2011	1.5
CoS-SIS workshop, Cotonou, Benin	2012	1.5
Cooperation or Conflict, Wageningen, The Netherlands	2013	0.9
Seminars and Workshops		
WIAS Scientific Day Wageningen, The Netherlands	2010	0.3
NPT-146/NUFFIC Workshop, Cotonou, Benin	2010	0.9
Symposium of Abomey Calavi University, Akassato, Benin	2011	1.5
WIAS Scientific Day, Wageningen, The Netherlands	2013	0.3
Presentations		
WIAS-Science Day, Wageningen, The Netherlands	2010	1.0
NPT-146/NUFFIC workshop, Cotonou, Benin	2010	1.0
Crocodile Specialist Group Workshop, Sri Lanka	2013	1.0
CoS-SIS workshop, Wageningen, The Netherlands	2009	1.0
CoS-SIS workshop, Bamako, Mali	2010	1.0
CoS-SIS workshop, Cotonou, Benin	2010	1.0
Symposium of Abomey Calavi University, Benin	2011	1.0
CoS-SIS workshop, Elmina, Ghana	2012	1.0
WIAS Scientific day, Wageningen, The Netherlands	2013	1.0
Conference-Cooperation or Conflict? Wageningen, The Netherlands	2013	1.0
Disciplinary and interdisciplinary courses		
An overview of the CoS-SIS Programme	2009	1.5
Research design and method to develop a research proposal	2009	1.5
Innovation systems: new ways of thinking about innovation	2009	1.5
Technology and institutional change	2009	1.5
Social institutions and innovation	2009	1.5
Re-examining the CoS-SIS Programme	2009	1
Nature of knowledge, action research, ß and ɣ sciences in research	2009	1.5
International discourse on development	2009	1.5

Advanced statistics courses		
Introduction to R for statistical analysis	2009	0.6
MSc level courses		
Methods, techniques and data analysis of field research	2009	4.0
Sustainable Development of Animal Systems	2009	6.0
Communication & Persuasion	2009	6.0
Professional Skills Support Courses		
Competencies for integrated Agricultural research	2009	1.0
Techniques for Scientific Writing	2013	1.2
Mobilizing your scientific network	2013	0.5
Research Skills Training		
Preparing own PhD research proposal	2009	6.0
Training on the handling of crocodile, Crocodile Farm, Pierrelatte, France	2012	1.0
Didactic Skills Training		
Supervising one BSc thesis, Abomey Calavi University, Benin	2011	1.0
Education and Training Total		**66**

* one ECTS credit equals a study load of approximately 28 hours

THE COS-SIS RESEARCH PROGRAMME

What is CoS-SIS?

What is CoS-SIS?

1. Definition and Purpose

Convergence of Sciences-Strengthening Innovation Systems is an action research programme in Benin, Ghana and Mali. It carries out scoping and diagnostic studies, agrarian system analyses and participatory field experiments with innovation platforms at the local, district and national levels. Its purpose is to identify pathways for creating opportunity for smallholder farmers in West Africa. Focusing on the enabling conditions at levels higher than the field and farm, the Programme supports sustainable intensification of smallholder farming for food security.

2. Partners and Funding

CoS-SIS is a partnership among the *Université d'Abomey-Calavi* at Cotonou, Benin; the *University of Ghana* at Legon, Ghana, and the *Instut Polytechnique Rural de Formation et Recherche Appliquée*, at Katibougou, Mali; and *Wageningen University*, and the *Royal Tropical Institute* in the Netherlands. It is funded to a total of € 4.5 million for six years (end 2008-mid 2014) by Dutch International Cooperation.

3. History and future

CoS-SIS is the second phase of CoS. CoS1 (2001-2006) focused on participatory technology development (PTD) in Benin and Ghana. It showed that smallholders can capture only limited benefits from even the best-adapted and appropriate technologies because of their constrained opportunities. Hence CoS1 researchers started to experiment with institutional change (in addition to their agronomic work). Their early results inspired CoS-SIS in that they convincingly demonstrated that institutional change is both important and feasible. CoS-SIS is currently supporting CORAF in implementing its IAR4D strategy with its West African partners.

4. Personnel

CoS-SIS employs eight post-doc Research Associates (RAs), recruited part-time from national research organisations and universities, and nine African Ph.D. researchers. Some of the RAs are graduates of the COS1 programme. The RAs facilitate concerted action and Innovation Groups (CIGs) (multi-stakeholder platforms composed of key actors in an agricultural domain) at the district and national levels to experiment with institutional change. The Ph.D. researchers work at community level with groups of local people to analyse constraints and experimentally develop livelihood opportunities. The doctoral research feeds into the deliberations of the CIGs. The work is overseen by National, Regional and International Programme Coordinators, who together form the Programme Management Committee (PMC). Responsibility for each country programme rests with a Programme Management Team (PMT) composed of senior representatives of universities, ministries, R&D organisations, the private sector, NGOs and FBOs. The PMTs and coordinators are proving to be high-level networkers and important advocates of the institutional change initiated by the CIGs and PhDs.

5. Domains reflect national priorities

- *Benin*: cotton, oil palm (inter-cropping oil palm and annual crops, and the oil palm seed system) and integrated water management (agro-pastoral dams in the North, and rice production in valley bottoms in the South);
- *Ghana*: palm oil and cocoa (work in the domain of small ruminants ended when the RA was promoted to another location by his home organisation);
- *Mali*: integrated water management, integration of crop and livestock production (both in the Office de Niger), and shea butter (*karité*).

6. Key activities

- Identifying key constraints that specific categories of smallholder farmers and processors experience when trying to improve their livelihoods and incomes through productive or value adding activities.
- Identifying and researching the institutional reasons for the constraints at the local and higher system levels.

- Identifying key actors, networks and mechanisms that maintain the constraints, as well as entry points for action to by-pass, or transform the institutional context to overcome them.
- Assembling multi-stakeholder platforms of key actors who can be expected to engage in institutional change in their respective domains.
- Enabling platform actors to experiment with institutional arrangements.
- Institutionalising achievements in university curricula, the programmes of research institutes, government policies, the structure of agricultural industries, and arrangements among enterprises and services and in value chains.
- Researching the processes of change and the work of the CIGs by means of real-time monitoring and a form of modified causal process tracing, based on two declared theories of change (intervention theory focused on internal and external activities and relationships of the CIGs; and power theory, focused on networks that have power to change or maintain institutional contexts linked to each domain).
- Ensuring that the outcomes of the action research are published and disseminated through international scientific media, and shared with local, national, and regional government agencies and political decision makers.

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