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The use of ecosystem services to value wetlands in the Senegal River Basin - a pilot study

A&W-report 2111

Commissioned by

OMVS
ORGANISATION POUR LA MISE EN VALEUR DU FLEUVE SÉNÉGAL

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Front cover
Senegal River at Gaani village, Mauritania. Photo by Erik Klop

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Contents

1 Introduction

1.1 Introduction and goals

The Senegal River (1,800 km) is one of the major waterways of West Africa, passing through Guinea, Mali, Senegal and Mauritania (figure 1.1). Located in the water scarce Sahel, the river is a key resource for development in terms of energy, food production and water. As the region develops the pressure on the use of water is increasing, involving amongst others hydropower, irrigated agriculture and navigation. The management of the river is governed by the *Organisation pour la Mise en Valeur du Fleuve Sénégal* (OMVS, www.portial-omvs.org). In narrow consult with the relevant stakeholders, the OMVS is the key convener for the development of a strategy on the integrated management of water resources in the basin.

Wetlands in the Senegal River Basin are a type of 'natural infrastructure' that underpin sustainable development, by regulating water flows and water quality, supplying communities with water, and providing resilience to communities when hazards such as drought and floods occur. As such these wetlands are important for supporting many different societal stakeholders. Rural and peri-urban communities in particular rely upon their services. As a consequence these communities are vulnerable to water management that affect wetlands. Wetlands International Africa (www.africa.wetlands.org) has put much effort in advocating the role and function of wetlands for ecosystems, biodiversity and society.

Wetlands in the basin have typically been managed so far to maintain biodiversity, in particular the wetlands with a protected status. However, wetlands offer much wider values that are beneficial to people, often called *ecosystem services.* The OMVS and Wetlands International Africa acknowledge that wetlands in the Senegal Basin play an important role in the livelihoods of riverine communities. Also, wetlands might be pivotal in mitigating future challenges such as climate change, and strengthen the resilience of local communities. Both organizations recognize that this important role of wetlands needs to be taken into account in planning, decision making and the operational management of the river.

In this context, OMVS and Wetlands International have decided upon two main actions to carry out, of which the current report is one of the results:

1. Knowledgebase development, based on the notion that informed decision making with regard to development in the basin requires a stronger knowledgebase. Although the Senegal Basin has many wetlands, there is a lack of information on their location, characteristics, the services and benefits they provide, their values and their vulnerability. In particular an assessment is needed on wetland ecosystem services related to water and food security and community resilience in response to water shortage and climate change.
2. Advocate for wetlands to be part of sustainable development planning in the Senegal River Basin. Based on a thorough analysis, the OMVS and Wetlands International can develop a strategy on how wetlands can play a structural role in mitigating future challenges. The first step in this process will be to do a pilot study to show how the added value of wetlands for communities in the basin can be assessed, next to their significance for ecosystems and biodiversity.

Figuur 1.1 The Senegal River Basin, showing the main river and tributaries, and the catchment area in Mauritania, Senegal, Mali and Guinea.

Since the entire basin is too large and the timeframe and resources are not sufficient to enable implementation of these actions for the whole basin on short notice, the choice was made to focus on three pilot areas. The study presented in this report aims to I) provide insight in how the benefits of wetlands for communities can be assessed efficiently, and II) to show the ecosystem services of wetlands in these pilots and their significance to the human population, as well as the physical context. Since this is a pilot study we pay close attention to the methods used. This study is part of a larger effort of Wetlands International Africa and the OMVS with the objective to ensure better knowledge of wetlands of the Senegal River Basin, highlighting their importance to human wellbeing and to provide a sound basis for policy makers.

1.2 Background

Significance to policy

The Senegal River Basin is managed by the *Organisation pour la Mise en Valeur du Fleuve Sénégal* (OMVS) which is an international institution created in 1972. Its main tasks are safeguarding the economies of member countries, reducing the vulnerability of the population with regard to the use of water resources, and environmental protection and conservation of the ecosystems in the basin. On 20 July 2012, a memorandum of understanding was signed between Wetlands International and OMVS. Through this, WI and OMVS recognize that cooperation should facilitate the achievement of their common goals, i.e. removing constraints to the development of the Senegal River Basin whilst ensuring a healthy environment.

The Senegal River Basin has significant wetland resources whose health is largely dictated by the river itself. The wetlands hold huge values for the inhabitants of the basin by supporting the livelihoods and local economies of many thousands of people. There has been considerable development of water resources in the basin in the past that impacted on wetlands and those parts of society depending on them. The riparian states want to continue to develop the river's water resources to support the economy in the region. Irrigated agriculture for food security, energy production to support mining and growth of the urban population and improved upstream navigation to support trade and the economy are all key drivers. The remaining wetland resources ask for a delicate balance between these developments and an improved wetland management and restoration. Integrated Water Resources Management (IWRM/GIRE) is the key process to achieve this. A sound knowledge of the benefits and services delivered by the river and its wetlands, as well as a proper advocacy of these on a political level, helps to incorporate these values in the IWRM on a basin level. Moreover, it stimulates the engagement of the key stakeholders in wetland values – typically rural communities – in planning and implementation of existing frameworks.

Water management and SDAGE

The water from the Senegal River is of pivotal importance to millions of people, livestock and the biodiversity in the region. By 2025 nearly 10 million people are expected to live in the river basin, who are directly or indirectly dependent on the river's water supply for food, energy production and drinking water (OMVS 2011). The growing population and the associated rising demand of food and water all hinge upon the proper management of water resources and water consumption from the Senegal river and its wetlands. Agriculture accounts for over 90% of annual water consumption. At present, the annual water consumption by agriculture is around 1.4 billion m^3 but this is expected to rise to over 5 billion m^3 in 2025 (table 1.1). A vision with regard to the management and multiple uses of the water is described in the so-called SDAGE (*Schéma Directeur d'Aménagement et de Gestion des Eaux du fleuve Sénégal;* OMVS 2011).

Table 1.1 Estimated water consumption in 2025 by different users. The water consumption for mining refers mainly to the Faleme mine on the borders of Mali and Senegal; for simplicity this has been allocated here to Senegal. Source: SDAGE (OMVS 2011).

Sector	Mauritania	Mali	Sénégal	Guinée	Total
Agriculture	1350	237	3240	370	5197
Livestock	28	17	21	18	84
Mines and industry	0	0	235	0	235
Drinking water	63	6,5	53	7	130
Total	*1441*	*261*	*3549*	*395*	*5646*

The SDAGE describes the management of water resources, aquatic environments and ecosystems within the Senegal River Basin within a time frame up to 2025. This is based on the strategic ambition of the four member states to ensure water availability to the relevant stakeholders whilst adhering to the principles of integrated water resource management (IWRM). Some fundamental aims behind this strategy are:

- A better balance between stakeholder needs, uses, quality and quantity of resources in the basin (water, soil, forests, etc.) for sustainable development and the preservation of ecosystems and the environment of the Senegal River Basin;
- Control of the river water, both in quality and quantity, to ensure the safety and health of the human population as well as the proper functioning of aquatic ecosystems;
- Achieving food security by sustainable use of natural resources and ecosystem services delivered by the environment;
- Monitoring the state of the environment in the basin, in particular to be able to anticipate and adapt to potential impacts from climate change;
- Solidarity with neighbouring territories with regard to energy, transport, and the development of agriculture, industry and tourism.

In the implementation of Phase 3 of the SDAGE (the master plan with its actions), an important part was dedicated to conservation of the environment and improving knowledge of the basin. This includes baseline mapping of wetlands and an assessment of ecosystem services delivered by the basin’s rivers and wetlands. The current study provides a first step in developing methodology and main parameters to establish ecosystem services.

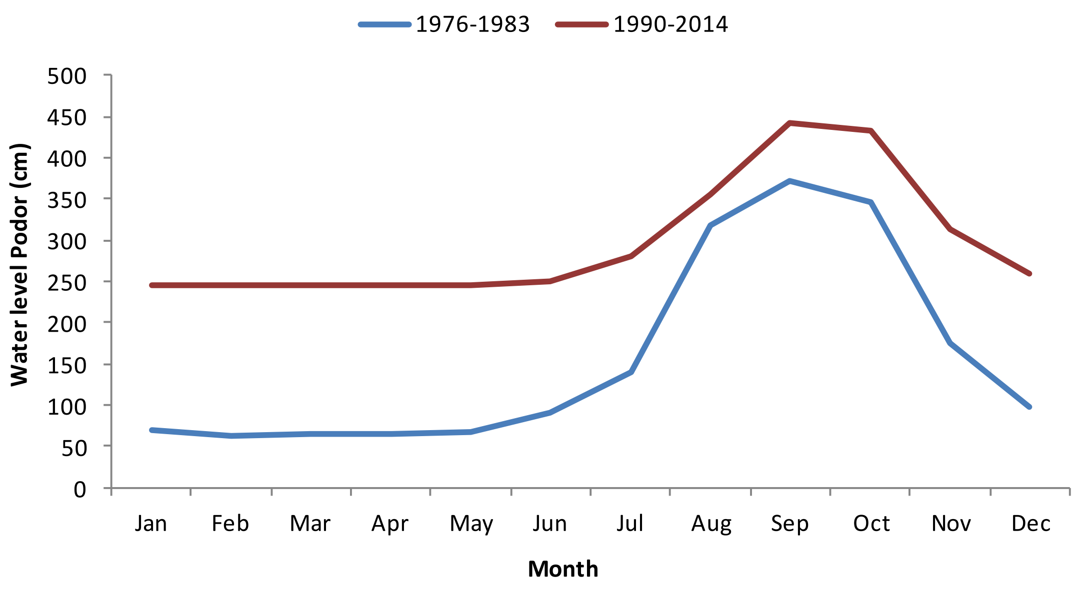
Hydrology and land use

The Senegal River is the second longest river in West Africa, passing through four countries and a wide range of climatic zones and ecosystems. Its main headwater is the Bafing, which originates in the Fouta Djalon mountains of central Guinea where annual rainfall measures over 2,000 mm. From Guinea it flows into the drier woodland savannas of western Mali, where it is joined by the Bakoye and continues in northwestern direction. Downstream from Bakel the river forms the border between Senegal and Mauritania, until it reaches the Atlantic Ocean near St Louis in northwestern Senegal. The northern stretch of the Senegal River is characterized by the arid landscapes of the Sahel where annual rainfall is less than 300 mm.

Land use in the Senegal River Basin is largely dictated by water supply from the river. In particular in the arid environments in northern Senegal and southern Mauritania, the river is the single most important factor that enables agriculture (e.g. rice, sugar cane) and other sources of food production in the area (e.g. vegetable farming, fishing). A major change in the hydrology of the river has been caused by the construction of two dams, i.e. the Diama dam in northern Senegal (completed in 1986) and the Manantali dam in western Mali (completed in 1988). The main purpose of both dams was to facilitate irrigation during the dry season and thereby to maximise self-sufficiency in rice production (Venema *et al*. 1997). Additional goals are the generation of hydropower at Manantali and (at Diama) to prevent the intrusion of salt water from the Delta into the upstream areas.

The impacts of the Manantali and Diama dams on water availability and land use in the Senegal River Basin have been described numerous times (e.g. Crousse *et al*. 1991, Horowitz & Salem-Murdock 1993, DeGeorges & Reilly 2006, Zwarts *et al*. 2009, Dumas *et al*. 2010). Before the construction of the dams, water levels in the river and Delta followed the flood pulse generated by the rains in the catchment area. Water levels at Richard Toll started to rise in July and reached a peak in September–October, after which they dropped again and reached the low dry season levels around January. Water resources in the river were driven by major fluctuations in rainfall. The severe droughts in the 1970s and 1980s – La Grande Sécheresse – acted as a 'watershed' in the management of the river's water resources, leading to the construction of dams and active water management within the basin.

Currently, the hydrological cycle is governed to a large extent by the releases at Manantali and water levels are being kept much higher and more stable throughout the year. This is illustrated in figure 1.2, which shows the average month maxima of water levels recorded at Podor. Before the construction of the dams, dry season levels did not exceed 70 cm and showed a five-fold increase to roughly 350 cm in the wet season. In contrast, since the 1990s dry season levels are kept high at roughly 250 cm, increasing to 400 cm in the wet season. This regime facilitates the year-round availability of water for irrigated agriculture, which has lead to a shift from traditional flood-recession agriculture (mainly sorghum) to intensive rice production in the Senegal River Valley (Dumas *et al*. 2010). The absence of the natural flood cycle also triggered a series of other environmental impacts, including major increases in the prevalence of waterborne diseases such as bilharzia (Jobin 1999), the spread of invasive plants like Cattail (*Typha australis*) and the degradation of wetland habitats (Zwarts *et al*. 2009).



Figuur 1.2 Mean maximum water levels (cm) per month in the Senegal River recorded at Podor, before (1976-1983) and after (1990-2014) the construction of the Diama and Manantali dams. Source: OMVS.

1.3 Study focus and research questions

As described in the previous sections, the overall purpose of this study is to identify and describe the main services delivered by wetlands to the people living in the Senegal River Basin, as well as the wider environmental and spatial context in which they operate. Also we attempt to evaluate the appropriate methods to assess these values. This information can provide guidance to both local stakeholders and policy makers in planning and decision making in the Senegal River Basin, for example with regard to climate change adaptation, water management, land use, environmental protection and food security.

A particularly useful method to assess and quantify the benefits of wetlands for people is through the concept of *ecosystem services*, i.e. the benefits that people derive from nature (Costanza *et al*. 1997). These ecosystem services include the provision of food and water, materials, biodiversity, spiritual values etc. Since the entire Senegal River Basin is far too large to do a proper ecosystem services assessment in this stage, this study was carried out in a number of pilot sites.

Ecosystem services can encompass a wide range of environmental benefits, ranging from the provision of construction materials to the aesthetic appreciation of a beautiful wetland. The focus in this report is primarily on provisioning services such as food production and drinking water, and (to a lesser extent) on regulating services. Cultural services (e.g. tourism, spiritual values) are not taken into account, or only mentioned briefly without meaning to underestimate them. Given the study objectives, this report attempts to answer the following questions:

1. Are ecosystem services an appropriate way to assess the value of wetlands to local communities, ecosystems and biodiversity? And what is the best approach to do so?
2. What are the main ecosystem services, and what is their economic value, delivered by the Senegal River and its wetlands in the different study sites?
3. How do these services relate to fluctuations in water levels and long-term changes in water availability?
4. What are the most important constraints and risks encountered by the users of these services?

In this report, we start by giving a brief overview of the concept of ecosystem services (chapter 2). The methodology is described in chapter 3. The subsequent chapters (4-6) describe the main results for each of the study sites, including a description of the site and its hydrological context, an analysis of water availability and an assessment of the most important ecosystem services. In addition, the economic value of these services is briefly described. A synthesis of the study is presented in chapter 7, which describes how the main findings of this study can be used in OMVS policy.

1.4 Acknowledgements

This study is part of the project “Sustainable food and water security in the Senegal River basin: the role of wetlands as natural infrastructure” funded by the Ecosystem Alliance and the *Organisation Mise en Valeur du Fleuve Senegal* (OMVS) and carried out by Wetlands International. Many people and organizations have contributed to this project by providing information, logistical support and valuable advice. First of all we want to thank Wetlands International (Ede/Dakar) and the OMVS for their support throughout this project. In particular we want to thank Cheikh Sarr (OMVS Senegal) and Mohammet Fadel (OMVS Mauritania) for their generous support, ideas and discussions during the field trip. Ousmane Sane drove us safely through towns and desert in northern Senegal and southern Mauritania. Leo Zwarts and Daan Bos (A&W) helped with data on ecology and land use and general discussion on ecosystem services. In Senegal and Mauritania we received valuable information and data from many people and organizations, in particular OMVS, Adama Fily Bousso (SAED), Sidy Fall (OLAG), Moussa Diop (Eaux et Forêts at St Louis), Sado Keita (Eaux et Forêts at Ndioum), Service Régional de l'Hydraulique at St. Louis and the Délégué Regional de l’Environnement at Rosso. Last but not least, our sincere gratitude goes to the villagers and village chiefs of

Gouelit, Gaani, Keke1, Nasra and Thielao for their great hospitality and willingness to share information on land use in the area.

Figuur 1.3 Local water use in the village of Gaani (Mauritania), located right next to the confluence of the Senegal River and the Laouvaja inlet.

2 Ecosystem services

2.1 Introduction

Since time immemorial the Senegal River is a lifeline for the people living in the region, providing a constant source of water, food, products (clay, timber) and plants for medical treatment. Local communities also draw a strong link to the river for their cultural identity. Today we denote the benefits that people derive from the presence of wetlands in the Senegal River Basin as *ecosystem services* (Costanza *et al*. 1997, Levine & Chan 2011, EU 2014). Besides goods like biomass or drinking water, ecosystem services may also refer to more indirect benefits like flood protection, climate regulation, maintenance of biodiversity, etc.

The concept of ecosystem services was brought into widespread use by the Millennium Ecosystem Assessment (MA), a global initiative set up in 1999 to assess how ecosystem change would affect human well-being. The MA defines ecosystem services as “the many different benefits that ecosystems provide to people”. Despite the importance of these services to people, in the past many have been taken for granted, being viewed as free and infinite. However, it is now clear that the worldwide degradation of ecosystems is also reducing the services they can provide (MA, 2005). The ecosystem services concept provides a starting point towards defining, monitoring and valuating such services. Assessing and quantifying these services not only addresses the importance of protecting ecosystems, it can also provide decision makers with quantitative data on the value of doing so.

Following the MA, the Economics of Ecosystems and Biodiversity (TEEB) initiative was launched in 2007. Centered on economic valuation, TEEB aims to help decision makers recognize the economic benefits of biodiversity and the growing cost of ecosystem degradation (TEEB, 2010). In 2012, the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES) was established as an independent intergovernmental body open to all member countries of the United Nations (Ratified by Senegal, Mali and Mauritania). IPBES provides a mechanism recognized by both the scientific and policy communities to synthesize, review, assess and critically evaluate relevant information and knowledge generated worldwide by governments, academia, scientific organizations, non-governmental organizations and indigenous communities.

Ecosystem services are usually grouped in the following categories (see references above and figure 2.1):

- Provisioning services that relate to products obtained from ecosystems such as food, timber, water, fuel etc;
- Regulating services that relate to benefits obtained from the regulation of ecosystem processes, e.g. carbon storage, disease control, water purification, pollination etc;
- Supporting services which are necessary for the production of other ecosystem services. These include services such as nutrient recycling, primary production and soil formation These services make it possible for the ecosystems to provide services such as food supply, flood regulation and water purification;
- Cultural services that relate to non-material benefits such as religious and spiritual values, tourism, aesthetic values etc.

Ecosystem Services Provided by or Derived from Wetlands

Services	Comments and Examples
Provisioning	
Food	production of fish, wild game, fruits, and grains
Fresh water*	storage and retention of water for domestic, industrial, and agricultural use
Fiber and fuel	production of logs, fuelwood, peat, fodder
Biochemical	extraction of medicines and other materials from biota
Genetic materials	genes for resistance to plant pathogens, ornamental species, and so on
Regulating	
Climate regulation	source of and sink for greenhouse gases; influence local and regional temperature, precipitation, and other climatic processes
Water regulation (hydrological flows)	groundwater recharge/discharge
Water purification and waste treatment	retention, recovery, and removal of excess nutrients and other pollutants
Erosion regulation	retention of soils and sediments
Natural hazard regulation	flood control, storm protection
Pollination	habitat for pollinators
Cultural	
Spiritual and inspirational	source of inspiration; many religions attach spiritual and religious values to aspects of wetland ecosystems
Recreational	opportunities for recreational activities
Aesthetic	many people find beauty or aesthetic value in aspects of wetland ecosystems
Educational	opportunities for formal and informal education and training
Supporting	
Soil formation	sediment retention and accumulation of organic matter
Nutrient cycling	storage, recycling, processing, and acquisition of nutrients

* While fresh water was treated as a provisioning service within the MA, it is also regarded as a regulating service by various sectors.

Source: Ecosystems and human well-being: Wetlands and water – Millennium Ecosystem Assessment / p2

Figuur 2.1 Categories of ecosystem services delivered by wetlands. Source: ecosystems and human well-being (MA 2005).

2.2 Ecosystem services in the Senegal River Basin

The Senegal River, a lifeline

As mentioned in the previous Section, since historical times the way of living of communities in the Senegal River Basin is linked to the river, and their livelihoods largely depend on the river's resources. In particular in the arid part of the basin, with highly fluctuating precipitation patterns within and between years, the river is the only secure source of water. The river is not only a daily source of water (figure 1.3) but also provides the basis for production of fish, grains and fruits. For example, next to the farming of rice or sorghum in the river bed, the grains of floating *Echinocloa* grasses (*E. colona* or *E. longastaminata,* sometimes called bourgou) or the grains of the Water lilly (*Lotus ssp*., *Nymphea ssp*.) – Nénuphars – are used as food by the local communities. The river is providing the environmental conditions for several flood recession crops that are located in the river bed which remains sufficiently moist to sustain a full crop cycle. Also other crops, such as onions, aubergine and cabbage, are sown and harvested in the river bed. This service was and is essential to the riverine communities.

Especially in the northern part of the basin the river bed is providing grazing opportunities for cattle. The short growing cycle of annual grasses in the Sahel means that high-quality forage is limited to the actual growing season and a short period following the end of the rains (Senock & Pieper 1990). In the past, flooded pastures were present on a much wider scale, but still the possibility for pastoralists (Peulh) to herd their cattle near the river in the dry season is important. The availability of these pastures is critical to maintain the carrying capacity for cattle in a much wider region than just the riverine areas.

Parts of the river bed are covered by flood forest, in particular *Acacia nilotica*. Although the current stands of flood forests constitute only a fraction of that in the past, they constitute an important source for communities and serve as key habitat in the river's ecosystems. The trees provide timber for the local population. The flooded parts also function as spawning areas for fish when flooded. *Acacia* trees are valued for more reasons by the local communities. During flowering they attract bees for pollination; local people put beehives in the trees to harvest honey. In addition, products from trees play an important role in all kinds of medical treatments (Arbonnier 2000). From a cultural point of view, living in a riverine environment influences many aspects of life and tradition, varying from north to south with rainfall and ethnic groups. The trees host important biodiversity, also on an international level (Zwarts *et al*. 2009, Zwarts *et al*. 2015).

Focus on provisioning and regulating ecosystem services

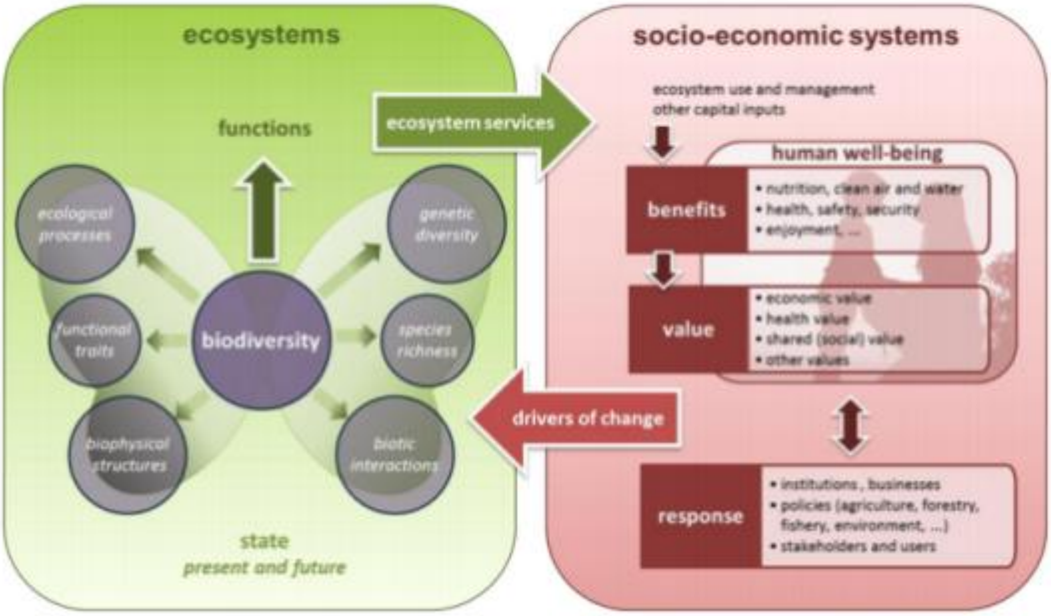
It is widely recognized by the key players in the Senegal River Basin that the added value of wetlands to communities, above their undisputed value to (international) biodiversity and ecosystems, should take a stronger role in planning and decision making. In this respect the potential contribution of ecosystem services to mitigate climate change and changes in future water management is important. The OMVS is much aware that the basin is facing major challenges to meet increasing demands for food, water and energy by a growing population. To balance these needs the management of land and water use requires an integral evaluation of natural resources in the basin. An assessment of wetland ecosystem services related to water and food security is a logical step in this process, as explicitly acknowledged in the SDAGE. Information on ecosystem services in the basin can provide tools to stakeholders and policy makers with regard to climate change adaptation, water management, land use, environmental protection and food security.

From the perspective of communities in the Senegal River Basin, provisioning and regulating services are most obvious to daily life, and highly relevant in terms of resilience to future changes including climate change. A significant part of these service are directly linked to the flood cycle and inundated area of the river, and are henceforth to water management within the basin. In this report we focus on the provisioning and regulating services.

2.3 Assessment of ecosystem services

A well-known and widely used framework to assess ecosystem services is given by the Working Group on Mapping and Assessment of Ecosystems and their Services (MAES; EU 2014). The MAES framework is depicted in figure 2.2. The left-hand part of the diagram in figure 2.2 consists of the characteristics and functions of the ecosystems present in the study sites. Information on the spatial location, biodiversity, ecological processes and the ecosystem functions forms the basis on which the assessment of services can be done.

The socio-economic components of the ecosystem services assessment are shown in the right-hand side of figure 2.2. This part consists of the identification of benefits and economic values, and drivers of change such as land degradation and climate change.



Figuur 2.2 Conceptual framework for the assessment of ecosystem services. Source: EU 2014, http://biodiversity.europa.eu/maes

The MAES framework can be broken down into the following steps:

1. **Identification and mapping** of ecosystems, land use and biodiversity. This step is the backbone of the entire assessment, allowing spatially explicit prioritisation and problem identification as well as serving as a communication tool with stakeholders.
2. Identification of the **ecological functions** from these ecosystems, which refer to the physical, chemical and biological processes within an ecosystem such as nutrient cycling, water retention etc.
3. Identification of the **ecosystem services and benefits**, i.e. the ways in which society can benefit from these ecosystem functions.
4. Assess the **monetary value** of these benefits.

Details on how these steps were carried out within this study are given in chapter 3.2.

3 Methodology

3.1 General approach

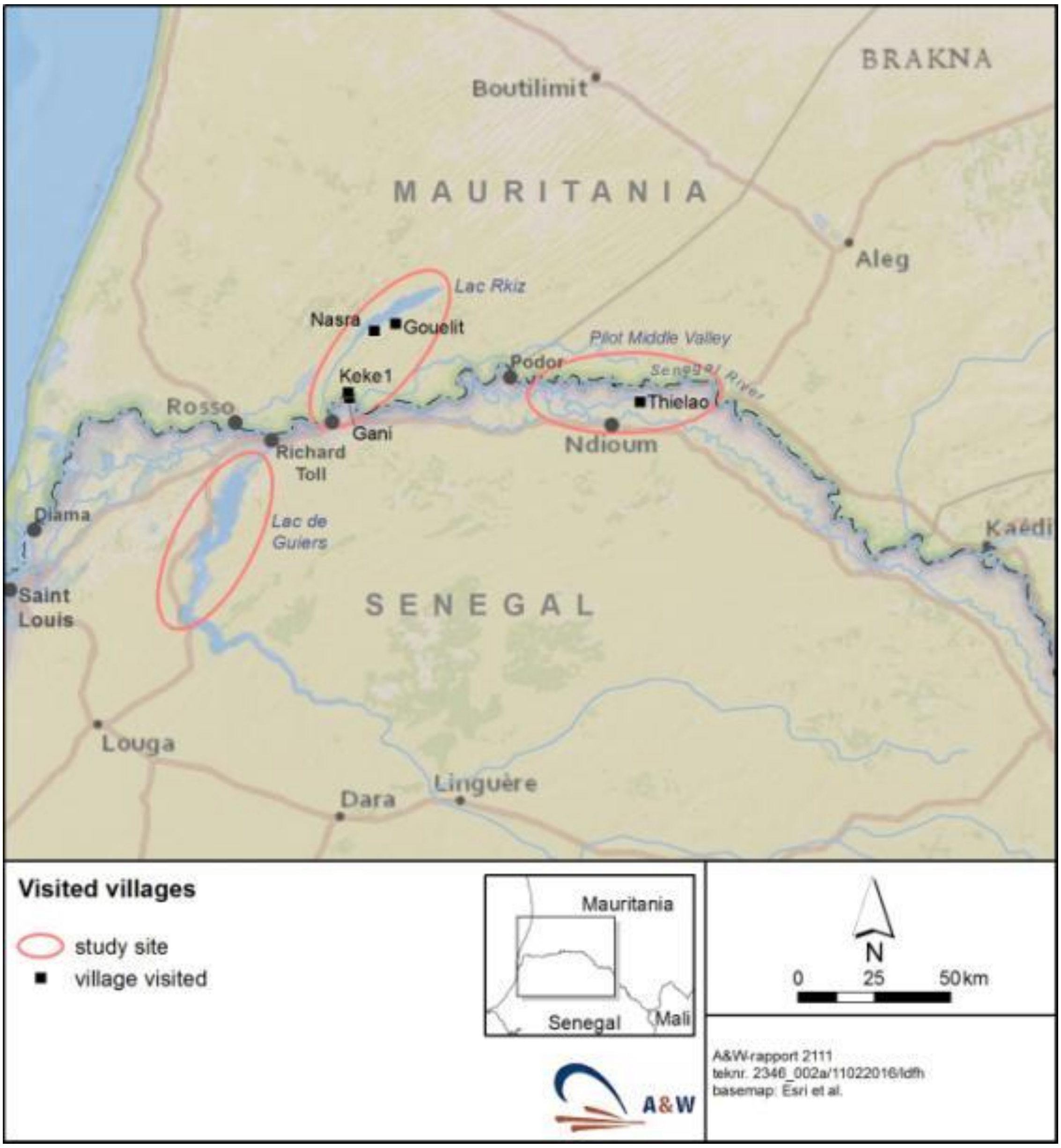
This study is part of the project “Sustainable food and water security in the Senegal River basin: the role of wetlands as natural infrastructure” in which ecosystem services of wetlands in the basin are examined more closely. This project is coordinated by Wetlands International Africa together with experts of the OMVS. In February 2015 a first mission was carried out and the general approach was discussed. This was followed by a second field mission in March 2015, during which the different pilot areas were visited. The field data from the pilot studies were combined with data from satellite imagery, resulting in the present report.

An important objective of this study was to examine if and how information on ecosystem services can contribute to managing future challenges such as climate change and upstream developments. Therefore, it was chosen to first do a pilot study and also to evaluate the suitable methododology to assess ecosystem services (section 3.2 and 3.3). In the pilots the methodology can be tuned to the availability of data and information, and the added value of this information to integrated management of natural resources can be evaluated. If this evaluation is positive, it might be worthwhile to scale up the assessment and do a wider study.

Pilot areas
The original aim of this pilot study was to assess wetland values and ecosystem services in the source area in Guinea, the middle valley in Mali and the delta region of the basin in Senegal. However, the ebola outbreak in Guinea (2014-2015) and safety reasons in Mali prevented doing field studies in the upper (Fouta Djalon mountains) and middle (Lac Manantali) parts of the basin. Consequently, three pilot sites were identified in northern Senegal and southern Mauritania (Figure 3.1). These sites are all located in the arid Sahelian part of the basin with an annual rainfall of roughly 200–300 mm, but differ in access to water from the Senegal River. The pilot sites are:

- <u>Lac R’kiz</u>, a shallow desert lake in southwestern Mauritania, roughly 60 km northeast of Rosso. Lac R’kiz itself is situated about 30 km north of the Senegal River, but is linked to the river by two shallow inlets.
- <u>Lac de Guiers</u> in northern Senegal, located roughly 17 km southwest of Richard Toll and connected to the Senegal River by the 17 km Taoué canal, and holding permanent water.
- <u>Ndioum area</u> in the so-called ‘Middle Valley’, which refers to the vast alluvial plain between the Senegal Delta in the west and Bakel (where the Falémé tributary joins the Senegal River) in the east.

The assessment of ecosystem services and ecological and economic significance of the three pilot sites is given in chapters 4–6. All these chapters start with a succinct description of the geographical and hydrological context in which these study sites are situated. From this contextual description the large differences between the Delta and the middle valley become evident, and it helps to judge the assessment of the study sites. After this section, we elaborate on water availability as main driver of ecosystem services. In addition, the ecosystem services are described as qualitatively as well as in terms of their economic importance. Each chapter ends with a short section on opportunities and challenges in the future.



Figuur 3.1. Location of the different study sites near Lac R'kiz, Lac de Guiers and the Middle Valley with the villages that were visited during the field work in March 2015.

For each of the study sites, we attempt to quantify water availability and associated ecosystem services for three time blocks:

1. The past, using as starting point the more or less the pre-drought period and the period before the main infrastructural interventions (1950-1960). Since good quality satellite maps from this period are mostly not available, we use information from the literature or try to reconstruct the past by using good flood years such as 1999 as a proxy.
2. The present, i.e. the actual situation based on field visits, good-quality satellite maps, and recent assessments of current land use practices and ecosystem services.
3. The future, based on qualitative assumptions about upstream developments and likely rainfall scenarios.

3.2 Water availability

Reconstruction of the past

Rainfall patterns in the Sahel during the 20th century have been erratic and subject to major fluctuations. Some pronounced wet periods occurred, mainly in the first half of the century, as well as long-lasting droughts such as in the 1970s and 1980s. Rainfall seems to be recovering in the last two decades, with 2010 being the wettest year since 1958 (Sanogo *et al*. 2015). In order to place contemporary patterns in water cover and ecosystem services in perspective, we try to 'reconstruct the past' and compare former patterns in water cover with the current situation. Ideally the historic situation would be analysed in the same manner and using the same remote sensing methodology as for the current situation (see below). The lack of good quality satellite imagery for these former time periods makes this, unfortunately, impossible. An alternative approach is therefore needed to assess water cover in the past. This can be done by a) making use of descriptive data from the literature or b) taking a recent year with good rainfall as a proxy for periods that were very wet like the 1950s.

Assessment of the present

The analysis of current patterns in water cover is facilitated by the ample availability of good-quality satellite images. Patterns in water availability in the study sites were assessed by calculating the surface areas of open water from satellite images in GIS. We used a series of Landsat TM, Landsat ETM+ and Landsat OLI satellite images from the period between 1984 and April 2015. Landsat images are widely used in remote sensing studies of the environment. Only images with low (<10%) cloud cover were selected to improve accuracy, since shadows from clouds may lead to misclassification of water surfaces. The 1980s and 1990s are represented by only a few good-quality images in a limited number of years, so these were omitted from the analysis as no reliable trends can be calculated for this period. The surface area of open water was extracted from the Landsat images using the Automated Water Extraction Index (AWEI) developed by Feyisa *et al*. (2014). The details of this process and corresponding GIS models are given in Appendix 1.

By analyzing a series of Landsat images throughout the year, an indication of the seasonality of water availability can be obtained. Although automated water extraction from satellite images is appropriate to assess areas of open water, it is important to note that areas with aquatic vegetation such as reedbeds, floating grass vegetations (*Echinochloa* ssp.) etc. are not taken into account by the AWEI index. We have corrected for this by mapping these areas manually.

Areas that are covered by water in all satellite images from different months can be considered to be permanently flooded, whereas areas that are covered by water in only a few images can be considered seasonally or occasionally flooded. We analyzed nine images from different months in 2014 and calculated the cumulative water cover. Areas covered by water in only one or two images were classified as 'occasional water', areas covered by water in 3 – 7 images were classified as 'semi-permanent water' and areas covered by water in 8 or 9 images were classified as 'permanent water'.

Patterns in water cover were related to annual rainfall and maximum water levels (source: OMVS) in the Senegal River at Podor. First, a Shapiro-Wilk test was used to test whether the data deviated from a normal distribution. Since none of the variables showed significant departure from normality, a Pearson correlation analysis was used to quantify the correlation between any two variables. All statistical analyses were done in the software package R.

Forecasting the future
Obviously no quantitative data are available for future trends in water availability, but some general patterns can be described based on qualitative assumptions about upstream developments and likely rainfall scenarios. From a multitude of studies on climate change in the Sahel region in the next decades, and in spite of many uncertainties, there is general consensus that climate change in the region will probably lead to an increase in temperature (higher evaporation), an increase in rain intensity but a decrease in the number of rain days (see e.g. IPCC 2014, IP2C 2015). In this study we limit ourselves to the question how ecosystem services are linked to water availability and how these might be affected by changes in water cover and flood frequency.

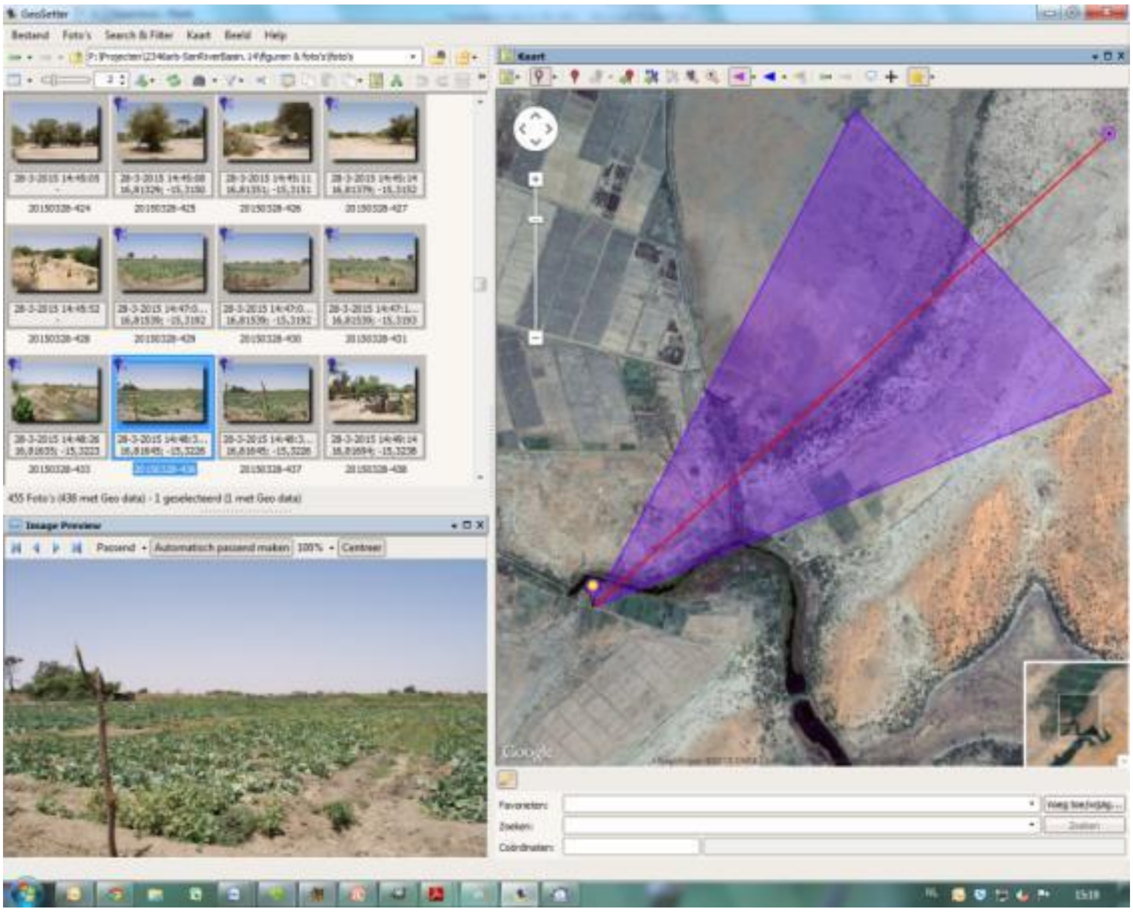
3.3 Ecosystem services assessment

To assess ecosystem services we follow the MAES framework (figure 2.2). Adopting an acknowledged framework facilitates the use of well-established methodology which will add to the credibility of the assessment. The different components of the diagram in figure 2.2 together constitute the ecosystem services assessment. This procedure can be broken down into the steps shown in figure 3.2, which are described in more detail below.

Figuur 3.2 Overview of the steps involved in the assessment of ecosystem services.

Step 1: Assessment of the ecosystems and biodiversity in the area (spatial mapping)
The first step in the process is the assessment and spatial mapping of ecosystems and land use in the study sites. Besides the classification of ecosystems and assessment of biodiversity, spatial mapping is a key element in this process (EU 2014). Having spatial information on land use is essential for spatially explicit prioritisation and problem identification (EU 2014). Furthermore, maps can be used as a communication tool with stakeholders and to visualise the locations where valuable ecosystem services are used or produced (EU 2014, http://biodiversity.europa.eu/maes).

An overview of ecosystems, biodiversity and land use patterns in and around the study sites was obtained by a combination of field work and the interpretation of satellite imagery. Ground truthing of ecosystems and land use units was done using either a handheld Garmin GPS unit or a digital camera (Nikon D3300) with attached GPS unit (Solmeta geotagger N3).



Figuur 3.3 The program Geosetter can be used to show georeferenced photos on a map. The photo is shown in the bottom left corner (in this case a cabbage field); the location is shown on Google Maps. The purple triangle on the map shows the angle of view. This facilitates mapping of ecosystems and land use.

This working method has the advantage of having geotagged photos available of the terrain at the study sites, which supports in an efficient way the mapping land use in the area. Geotagged photos were classified according to landscape and habitat (see below) and the locations visualized in specialized software (Lightroom and the freeware program Geosetter; Fig. 3.3).

The ecosystems (both natural and man-made) for the Senegal River Basin can be classified into habitats and land use units. For the study sites in this report, the most important habitats are arid Sahelian landscapes, wetlands and agriculture. The different land use categories were subsequently manually drawn on satellite images in GIS based on the ground-truthing data. For Lac de Guiers and the wider Senegal Delta, the classification of Zwarts *et al*. (2009, p. 115) was used. Biodiversity in the area was assessed using information from the literature, personal observations during the field visits, and census data from the African-Eurasian Waterbird Census (AFWC) coordinated by Wetlands International.

Step 2: identification of ecosystem functions, services and benefits

The second step in the process is to identify the relevant ecosystem functions, which refer to the physical, chemical and biological processes within an ecosystem (Costanza *et al*. 1997, Boyd & Banzhaf 2007, Hermann *et al*. 2011). For example, ecosystem functions in a forest include photosynthesis, nutrient cycling, water retention, CO_2 uptake, provision of habitat, sustaining biodiversity etc. Ecosystem functions can be grouped into four main categories (De Groot *et al*. 2002):

1. Regulation functions: these functions refer to the capacity to regulate essential ecological processes such as bio-geochemical cycles;
2. Habitat functions: natural ecosystems provide refuge and habitat to organisms and thereby contribute to biodiversity;
3. Production functions, such as photosynthesis and nutrient uptake in order to produce living biomass;
4. Information functions, which refer to providing opportunities for reflection, spiritual enrichment etc.

From these functions, various services and benefits can be deduced. A widely used distinction between functions and services/benefits is that the functions are value-neutral, whereas the services and benefits have value to society (http://www.ecosystemvaluation.org). In other words, ecosystem services are the beneficial outcomes of ecosystem functions (Boyd & Wainger 2003). In the forest example, photosynthesis leads to primary production (the accumulation of woody biomass), and water retention to constant water supply.

In this study, with the emphasis on arid or semi-arid environments, we focus on water availability as the key ecosystem service governing the ecology of the area and land use by local people. Data on water availability are calculated from satellite maps (see section 3.2), water level measurements by OMVS in the Senegal River and data on rainfall (e.g. LeBarbé *et al*. 2002, Zeng 2003, Ickowicz *et al*. 2012). Both seasonal and annual patterns in water availability are investigated; for more details see Section 3.2.

Step 4: From ecosystem services to benefits
The following step is to deduct benefits from the services that have been identified. The difference between ecosystem services and benefits is often not distinct, and several authors consider these to be the same (e.g. Costanza *et al*. 1997, Wallace 2007). Other studies (e.g. Boyd & Banzhaf 2007, Fisher and Turner 2008) argued that services are strictly ecological in nature, whereas benefits directly relate to human well-being and also depend on other inputs like capital. For example, photosynthesis (the ecosystem function) leads to the growth of woody biomass (the service), after which the timber can be harvested (the benefit). Similar examples are shown in table 3.1.

The benefits derived from the Senegal River Basin were assessed by conducting social interviews in several villages around the study sites. The interviews were generally conducted with the village chief and a number of people representing different user groups (fishermen, rice farmers etc). The interviews focused on the relation between land use patterns and water availability from the Senegal River. The following villages were visited (figure 3.1):

- Gaani, Mauritania (N 16.592, W 15.456)
- Keke 1, Mauritania (N 16.606, W 15.459)
- Nasra, Mauritania (N 16.788, W 15.380)
- Gouelit, Mauritania (N 16.811, W 15.314)
- Thielao, Senegal (N 16.579, W 14.560)

Tabel 3.1 Examples of the distinction between ecosystem functions, services and benefits. Based on Boyd & Banzhaf (2007).

Function	Service	Benefit
Photosynthesis	Accumulation of woody biomass	Provision of timber
Water purification	Healthy fish population	Fish harvest
Pollination	Plant reproduction	Commercial harvests
Habitat provisioning	Sustaining biodiversity	Wildlife tourism
Water retention	Availability of wetlands	Flood control

During the interviews the following issues were discussed:

- Types of land use (agriculture, cultivation of vegetable crops, livestock, fishing);
- Seasonal patterns in land use in relation to rainfall and inundation patterns;
- Estimated production, ratio subsistence and market-oriented production;
- Methods of irrigation (pomps, manual irrigation, recession agriculture);
- Perceived changes after construction of the Diama and Manantali dams;
- Problems encountered, e.g. changes in water quantity and quality, diseases etc.
- General information (number of families etc.)

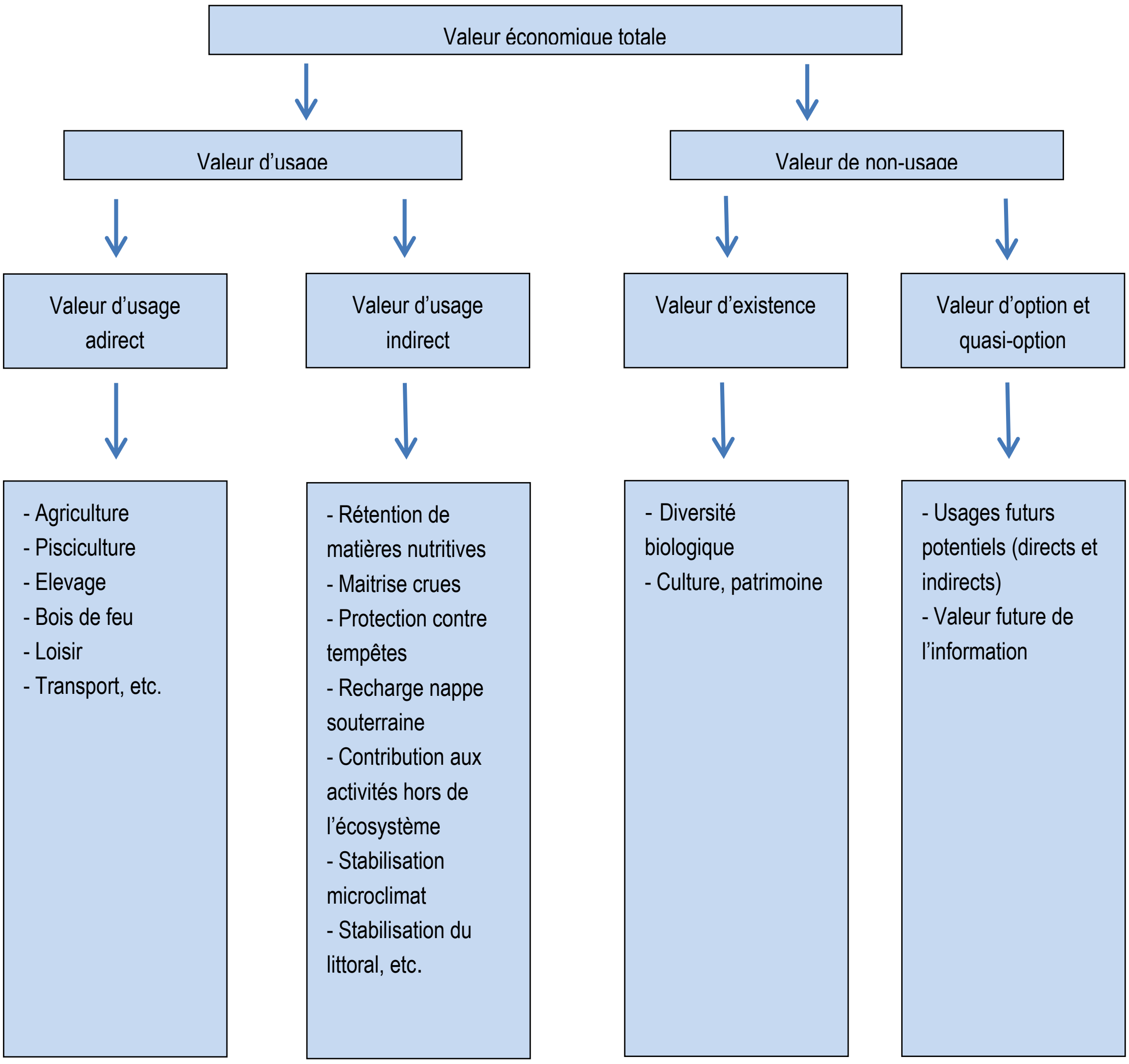
The information obtained from the interviews was supplemented by data from the literature and information obtained from several government agencies and organizations, including SAED, OLAG, Eaux et Forêts, etc.

Step 5: Economic valuation

A separate field mission was conducted by professor Abdoulaye Seck (Cheikh Anta Diop University, Dakar) in June 2015 in order to carry out an economic valuation of the relevant benefits. In total 416 households were interviewed in six villages in the area around Lac R'kiz: Gaani, Douze-Douze, Gouelit, Keke 1 and 2 and Madina Salam. The results are presented in a separate report (Seck 2015), and integrated in this report. The methodology is briefly summarized below.

The process for the economic valuation study can be split up in two parts, i.e. 1) the choice of the valuation methodology and 2) estimation of the monetary value. Barbier *et al*. (1997) provide an overview of the methodology for the economic valuation of wetlands. The total economic value distinguishes between use values (e.g. the provision of food and materials) and non-use values (e.g. biodiversity, heritage). The use values can be further categorized into direct use and indirect use values, in which the latter refers to e.g. nutrient cycling, flood control, shoreline stabilisation etc. This distinction corresponds well to the difference between provisioning services and regulating services.

A wide range of techniques is available for the estimation of monetary values (figure 3.4). For direct use values, which primarily involve harvested goods, market prices should serve adequately as measures of value (Barbier *et al*. 1997). It is more complicated to get a monetary estimate for indirect use values or non-use values since values like flood protection or biodiversity are not marketed. In these cases, the *willingness-to-pay* for these values has been estimated using contingent valuation. In this technique, a large number of users (i.e. villagers around the lake) are asked how much they would be willing to pay for a particular ecosystem service, in the *hypothetical* scenario that this service could be marketed. The willingness-to-pay can be expressed either in money or in natura such as harvested goods. More details can be found in Seck (2015).



Figuur 3.4 Classification of the economic value of wetlands. From Seck (2015), based on Barbier et al (1997) and Scodari (1990).

4 Lac R'kiz

4.1 Characterization and hydrological context

Part of the Lower Senegal Delta
Lac R'kiz is a shallow lake located in the Trarza region of southwestern Mauritania, roughly 60 km northeast of Rosso (figure 3.1). The lake measures 35 × 5 km and forms the southernmost part of the *Aftout ech Chergui* depression which is surrounded by a system of red sand dunes. The characteristic northeastern alignment of the dunes, caused by the prevailing wind regimes (Lancaster *et al*. 2002), result in a SW–NE orientation of the lake and surrounding landscape structures. Lac R'kiz is part of the Lower Senegal Delta; an arid environment with a Sahelo–Saharan climate: a long dry season (October–June) and short wet season, with most rains falling in August and September. Annual rainfall is roughly 200–250 mm, but is highly variable (see Ickowicz 2014). Unlike the now isolated desert lakes Lac Aleg and Lac Mal, Lake R'kiz is linked to the Senegal river by the Sokam and Laouvaja inlets (figures 4.1 and 4.2). These (uncontrolled) inlets branch off the Senegal River near the village of Gaani and are the main watercourses feeding the lake.

The region of the Lower Senegal Delta experienced fundamental changes in the recent past. Following the Great Droughts in the 1970s and 1980s dams were built and the once highly dynamic water regime was changed into a well controlled water system (see chapter 1). In the Lower Delta rice cultivations were developed and partly sugar cane. The changes in the water regime in the Senegal river, with higher dry season levels and less pronounced peaks, are relevant for water inflow to Lake R'kiz. In the following sections we sketch in short the historical and contemporary patterns in water availability.

Figuur 4.1. The Laouvaja inlet at the village of Gouelit, March 2015. The banks of the inlet are mostly dry and covered by blankets of Water primrose. In the far background the red sand dunes can be seen.

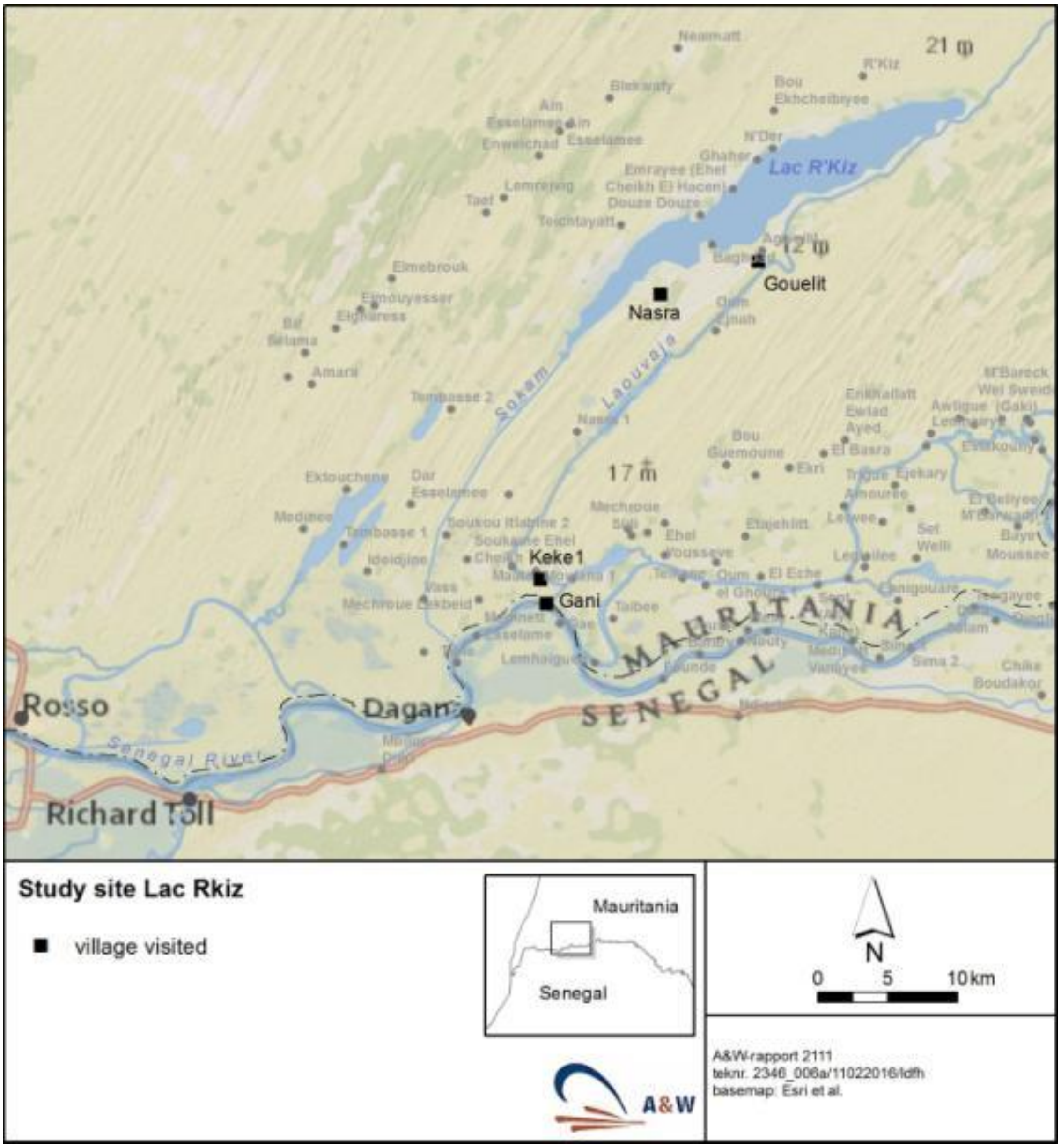


Figure 4.2. Location of Lac R'kiz (here shown when completely filled with water) and the villages that were visited during the field mission in March 2015.

Reconstruction of the past

Before the construction of the Diama and Manantali dams, the water level in Lac R'kiz followed the natural flood pulse in the Senegal River (Michel 1973). Water levels started to rise during the rains in August and September, and reached peak levels in the months of November and December. This peak occurred roughly six weeks later than in the Senegal River at Dagana (Santoir 1973). In wet years, water levels in the lake reached up to 3.5 m above sea level (figure 4.3), giving a maximum depth of around 6 m and a total flooded area of around 20,000 ha or 200 km^2 (Michel 1973). This large inundated area was caused mainly by river water and only partly from local rainfall. Flooding is possible in the area north of the lake, where the terrain slopes very gently and the nearest sand dunes are several kilometres away. The southern edge of the lake has a steeper slope and is bordered by sand dunes that prevent inundation of this area (Michel 1973). In dry years, the lake could dry out completely, as happened even in the relatively wet 1950s (e.g. in 1950 and 1954, see figure 4.3). In dry years, however, many parts of the lake dry out completely and during the 1970s the lake did not contain water for an entire decade (Service 1989).

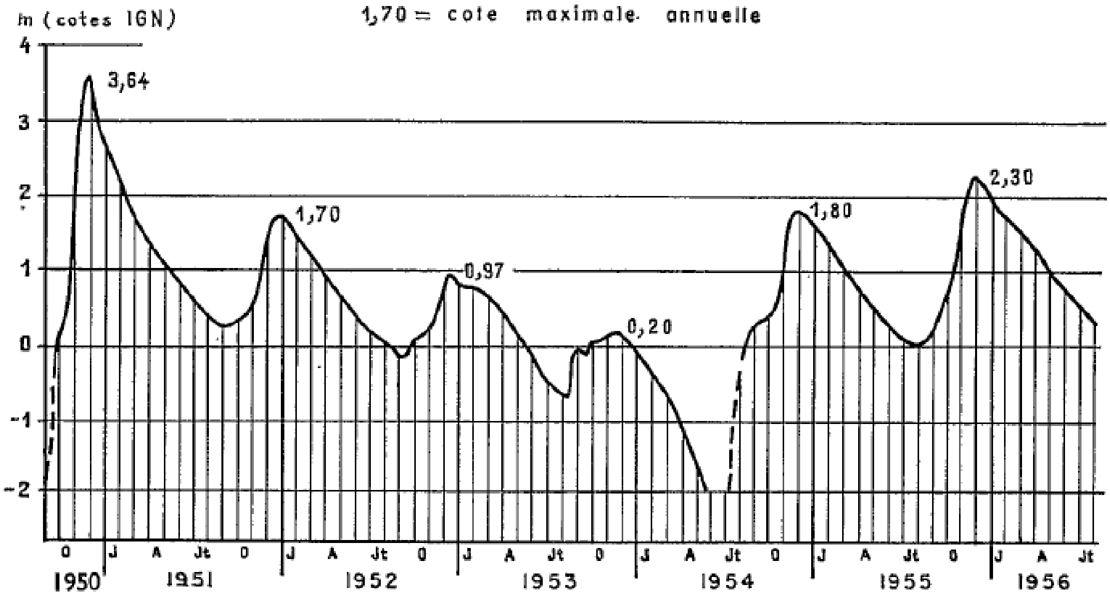


Figure 4.3 Annual fluctuations in water level at Lac R'kiz. Source: Michel (1973, fig. 33).

Present water levels and flooding

As in the past, the main water source of Lac R'kiz is the Senegal River. Figure 4.4 illustrates the dynamics of the water level at Richard Toll, about 30 km from the inlet to Lac R'kiz. Water levels in the past were highly dynamic, as illustrated by the example year 1958, while at present water levels are relatively stable throughout the year (see also section 1.2). Only years with heavy rainfall in the headwaters (such as 1999) are reflected in the fluctuations in the water level. The current water level is the result of the releases at Manantali and the dam level at Diama.

The current variation in water cover in and around Lac R'kiz is shown in figure 4.5. Inundation of Lac R'kiz starts in July at the onset of the rainy season. This peak lasts around three months. The water level in the Senegal River is rising in August–September, shown by inundation in 1999 of the Middle Valley (figure 4.6), but does not reach the lake yet until October–November. The arrival of the flood water causes a second peak in water cover in November (although for unknown reasons the calculated water cover in December is low). By the end of November, the water level in the Middle Valley has dropped significantly, due to evaporation and the releases at Diama. Lac R'kiz is still inundated at that time. Water cover is at its lowest in the second half of the dry season, between March and June.

Although the general pattern and timing of inundation at Lac R'kiz is comparable to what happened in the past (*avant-barrages*), current maximum water cover is no more than 10–20% of the values given by Michel (1973). It should be noted that some of the 'flooded' areas in Lac R'kiz are covered by aquatic vegetation. Although these areas may not hold open water, these wet environments may be important for small-scale agriculture or to stimulate grass regrowth used as grazing grounds for cattle.

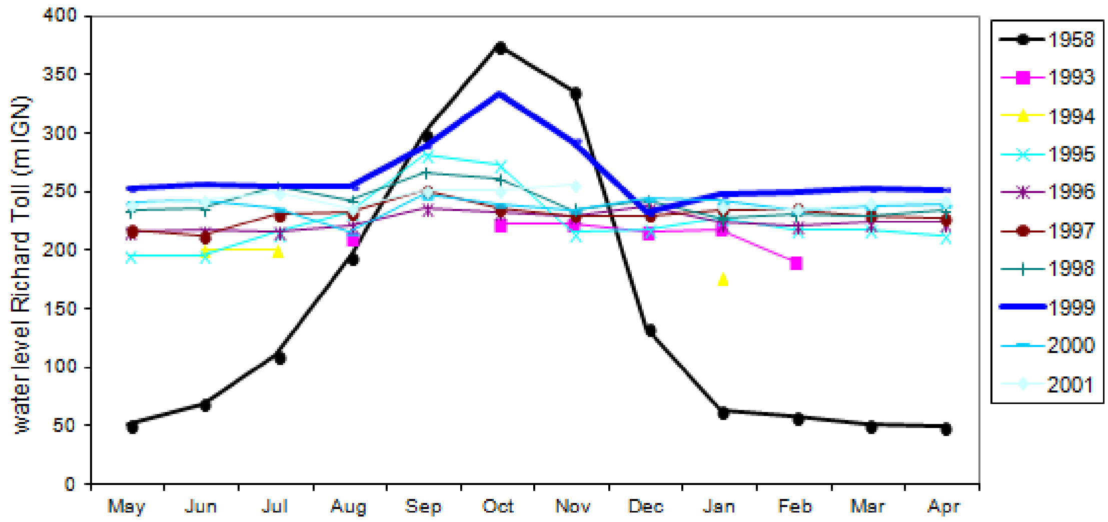


Figure 4.4. Water level at Richard Toll, 30 km downstream of the inlet to Lake R'kiz, in the 1990s, 2000 and 2001. As illustration also the predam level is shown, in the wet year 1958. The current water levels are comparable to these shown.

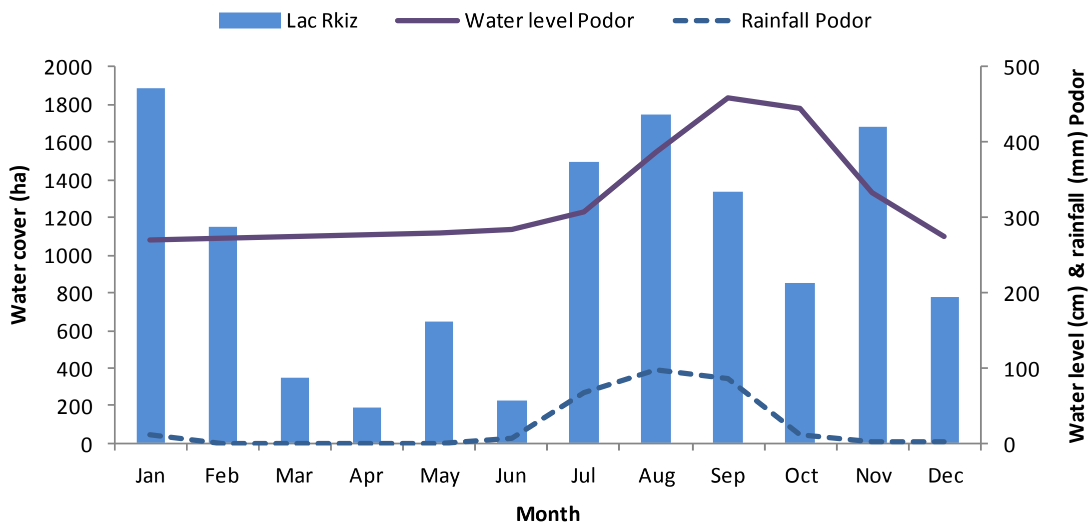


Figure 4.5. Mean maximum water cover per month in Lake R'kiz based on satellite imagery, based on the years 2001–2013. The bars refer to areas of open water (which have been extracted using the AWEI index of Feyisa et al. 2014) combined with areas of water covered by aquatic vegetation which have been manually mapped using the satellite images.

Today in most of the years, also in relatively dry seasons, the water level in the river at the location of the inlets to Lac R'kiz will vary around 200–300 cm. At that level, water feeds into the inlet system under gravity. However, the inlets are narrow and appear to be partly blocked by invasive *Typha* stands. In addition, over time the depth of the channel may decrease through sedimentation (organic layer of Typha remnants). The combined effect will be a decreased discharge to Lac R'kiz with corresponding smaller inundated areas.

During much of the year, the inlets hold water (mostly the Laouvaja) rather than Lac R'kiz itzelf. This is a result of the stable water level at around 200–300 cm in the river, meaning that also during the dry season the inlets are fed. The stable water level in the inlets has aggravated the development of Typha fields; this invasive plant species highly profits from stable (fresh) water levels, as has been seen in the Senegal Delta and Lac de Guiers (chapter 5, Zwarts *et al*. 2009). Based on nine satellite images from different months, no permanent water was observed in the lake in 2014, and most of the water cover in the lake was classified as 'occasional'. This means, that the lake ecosystem is still highly dynamic, which is characteristic for Sahelian wetlands. In the inlets, roughly 61% of the surface area of water was classified as either 'permanent' or 'semi-permanent'. As explained, this is linked to the permanent high water levels in the Senegal River.

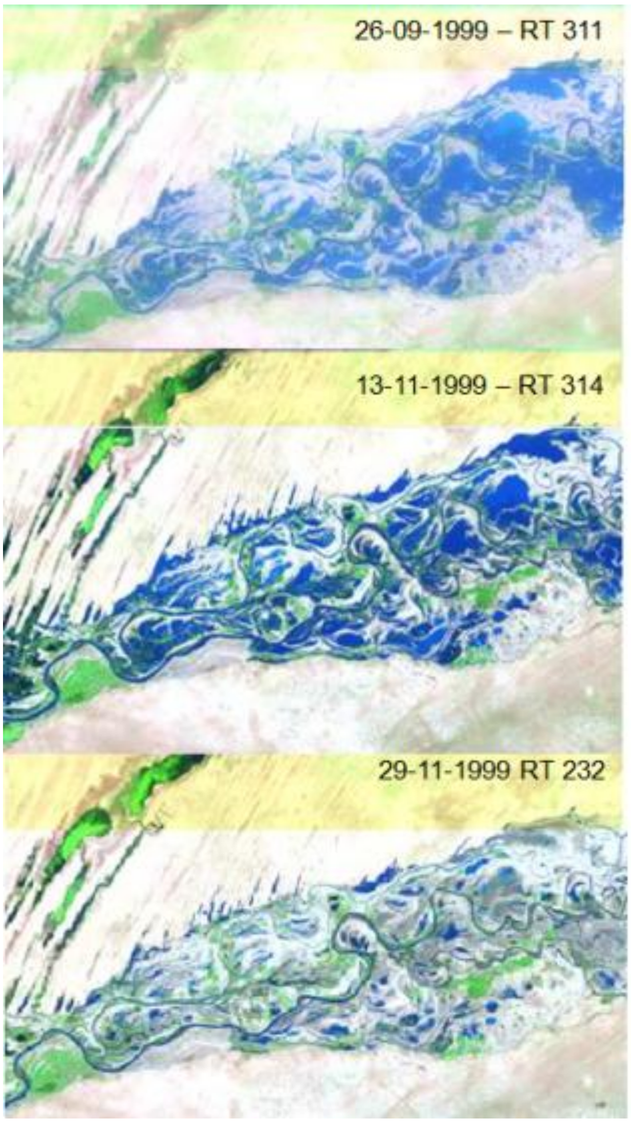


Figure 4.5. Satellite images of a part of the Senegal Basin between Richard Toll and Dagana. Images are shown from 26 September and 13 and 29 November 1999. This was a year with a very high precipitation, resulting in the highest floods recently. RT = mean monthly water level at Richard Toll, 30 km downstream the inlet to Lake R'kiz.

Current land use and habitats

Lac R'kiz is situated in the most arid environment of the sites in this study. With large parts of Lac R'kiz and the Sokam inlet being dry for most of the time, the Laouvaja inlet is the main source of open water in an otherwise very arid landscape. During the field visit in March 2015, much of the lake was dry and water levels in the Laouvaja near the village of Gouelit were very low.

The area around the lake consists of typical Sahelian ecosystems, including semi-desert, sand dunes and thorn scrub. Vegetation is generally sparse and dominated by *Balanites aegyptiaca*, *Acacia tortilis*, *Prosopis juliflora* and *Leptadenia pyrotechnica*. On disturbed ground, *Calotropis procera* is found and can be locally dominant such as in the dried-out lake south of R'kiz village. The dry parts of the lake are covered by sparse thornscrub and woodland (*Acacia* and *Balanites*), whereas the seasonally flooded areas are covered by semi-aquatic vegetation such as blankets of Water primrose (*Ludwigia sp.*). The margins of the Laouvaja inlet are locally covered by dense *Typha* and *Phragmites* reedbeds.

Several villages are dotted around the lake and its inlets (Fig. 4.2). The village of R'kiz is located at the northern tip of the lake. Several villages are found along the Laouvaja inlet, such as Gouelit (18 families, <100 people) which is located just south of the lake proper, Keke 1 (300 – 400 people) and Gaani (>3500 people) at the confluence of the Laouvaja and Senegal River.

4.2 Ecosystem services

All forms of land use in this arid landscape are directly linked to water provisioning by the Senegal River. Low rainfall and high evaporation rates mean that rain-fed agriculture is not feasible, making the system entirely dependent on water inflow through the inlets. Because of these conditions, the diversity of land use is typically low for such a Sahelian wetland and and restricted to the areas adjacent to the lake or its inlets. In the environs grazing is possible in low densities and timber is collected.

In terminology of the MAES framework (figure 2.2), the processes of water retention, water purification and habitat provisioning are the ecosystem functions provided by the river and its wetlands. The availability of water is by far the most important ecosystem service, which leads to several benefits such as irrigation of crops, rice farming, fish harvests etc.

A key ecosystem function in this respect is the dynamic nature of the floods, i.e. the seasonal variation in inundated area and water depth. Seasonally flooded grounds facilitate the cultivation of vegetable crops that would otherwise be completely dependent on active irrigation using diesel pumps, and provide grazing grounds to cattle from pastoralists. Besides these provisioning services, important regulating services are linked to flood dynamics including disease control (e.g. bilharzia), optimization of water quality, controlling the spread of invasive plants like Typha, and maintaining healthy wetland habitats.

Provisioning services

The most important provisioning services refer to the water itself (drinking, washing, irrigation) and the production of biomass (agriculture, fishing, livestock) that is generated by the water. Agricultural activities are restricted to areas near open water, in particular where possibilities for irrigation are limited to small-scale techniques such as small diesel pumps. Around the Laouvaja inlet, no more than a few tens of hectares are used for the cultivation of vegetable crops. Rice farming is also done at larger scales, but part of the rice field complex near Lac

R'kiz is abandoned. The location of the different land use units around the lake are shown in figure 4.8. The different forms of land use are described in more detail below.

1. **Vegetable crops**. This is one of the most important livelihood activities for all villages that have access to open water. A diversity of vegetables is being cultivated, in particular onions, tomatoes, cabbage, aubergines, chili pepper, carrots and okra (figure 4.7). The main season is the 'cold' season after the rains, from November to February, although some crops (e.g. chili pepper, okra, aubergine) are also cultivated in the hot summer months. The cultivation of vegetable crops is usually practiced at a fairly small scale, with mean plot sizes of 1.1 ha; over 92% of all agricultural activities are done at fields smaller than 2.5 ha (Seck 2015). As can be seen in figure 4.8, the cultivation of vegetable crops is restricted to a small strip around the Laouvaja inlet where the crops are irrigated either by hand or using small pumps powered by a diesel generator. The vegetable fields near Lac R'kiz are concentrated around the villages of Gouelit and Nasra, at the northern half of the Laouvaja with a total area of around 63 ha.

2. **Rice farming**. Irrigated rice production in Mauritania is concentrated in the Senegal River Valley, as most of the country is too dry to support rice farming. The main rice growing areas are located within a strip of 10 km of the Senegal River. Rice farming is by far the most important agricultural activity in the Senegal River Basin (see OMVS 2011); around 77% of the interviewed households around Lac R'kiz and the Laouvaja inlet are involved in rice farming (Seck 2015). As indicated by Seck (2015), roughly 26% of the rice harvest is used for own consumption (compared to no more than 6-7% for onions and tomatoes). Nearly 60% is sold at markets with the remaining part being used for remuneration in kind of farm labourers, stocks etc.

   Several areas around Lac R'kiz hav been designated for rice farming. Currently some 1,200 ha of rice fields are situated northwest of Gouelit village, but based on satellite images some 800 ha seems to have been abandoned. Abandonment may be caused for multiple reasons, most likely water scarcity, low yields and labour shortage. In December 2014, a loan of $34 million was granted by the Saoudi Fund for Development (FSD) for the development of over 6,000 ha of agricultural fields around the lake. This includes the development of 3,500 ha at the eastern side and 2,200 ha at the western side of the lake. It also includes the rehabilitation of 1,000 ha at the western side, probably the area northwest of Gouelit. The Islamic Development Bank apparently planned to finance the management of 2,400 ha of agricultural fields at the eastern side of the lake, but the status of this project is unknown.

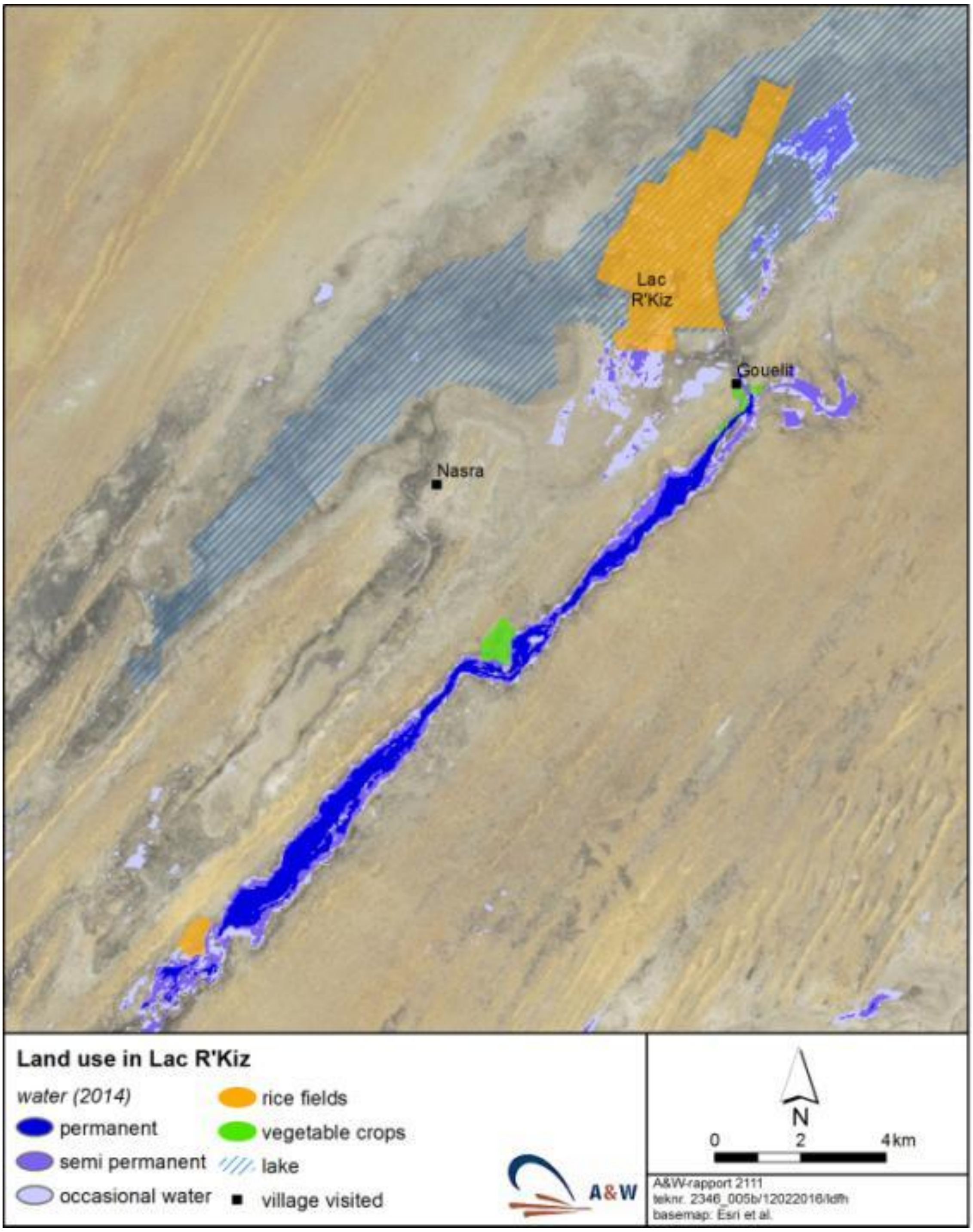
3. **Fishing** as a livelihood had become concentrated in the villages of Gouelit, Douze-Douze and Gaani. Due to its location directly adjacent to the Laouvaja, fishing is one of the main livelihood activities in Gouelit and is practiced by most villagers. It is often combined with the cultivation of vegetables; according to a study for OMVS (2010), there is a tendency to switch to the cultivation of vegetables with declining fish harvests. The fish harvest is used for both subsistence (10%) and to generate income by selling the surplus at markets (>80%) in surrounding villages and in Rosso.

4. **Livestock**. The potential for livestock around Lac R'kiz is limited by the availability of good-quality forage, like elsewhere in the Sahel. Less than 40% of the households interviewed by Seck (2015) are involved in livestock. Livestock production in and around the villages is strictly sedentary in character, where all animals are being kept within a few kilometers of the village. Sedentary livestock seems to consist mostly of

goats, with smaller numbers of sheep and cattle. In addition to these resident animals, the wider area is used by transhumant Peulh who migrate through the area with unknown numbers of Zebu cattle. According to the people in Gouelit and Keke 1, the availability of grass and browse in wet years is sufficient to sustain their sedentary livestock. However, during dry years forage availability may become limited and the villagers need to buy supplemental feed for their animals. Another problem is that during periods of food scarcity, the goats start to browse on cultivated crops like cabbage.

5. **Timber and charcoal**. The wooded areas surrounding Lac Rkiz provide timber for local use and wood for charcoal. Parts of the lake surrounding are densely populated by Acacia trees (mostly *A. tortilis*) and *Balanites aegyptiaca*, both indigenous trees used by the local communities.

Figuur 4.6 Vegetable fields adjacent to the Laouvaja inlet, near Gouelit village.



Figuur 4.5 Land use around Lac R'kiz, based on data from the field visit and Landsat images. The total area of rice fields is around 1,200 ha and that of vegetable fields around 63 ha. The shaded area depicts the approximate lake area when fully flooded (source: OMVS).

Regulating services
In addition to providing water and food, some important regulating services are provided by the water in Lac R'kiz and its inlets. These services refer to a wide range of benefits that operate on various spatial and temporal scales. Regulating services like disease control and maintenance of biodiversity are important to the livelihoods of local people, but also have implications on much larger scales.

As mentioned before, the seasonal variation in flood dynamics is an essential ecosystem function to maintain or generate these services. Stated otherwise, in the absence of natural flood dynamics many of these regulating services (as well as some of the most important provisioning services) would decrease or disappear. Although regulating services were not comprehensively assessed in this pilot study, a concise selection is given below.

1. **Disease control**. The importance of disease control can be illustrated by the prevalence of bilharzia in the area. This waterborne disease is caused by *Schistosoma* flatworms that are transmitted by a snail that occurs in stagnant or slow-moving water. Before the construction of the Diama and Manantali dams, the snail *Biomphalaria pfeifferi* which is host to the flatworms, was never found in the middle Senegal River Basin (Jobin 1999). However, the steady water regime after the dams were built has led to a dramatic increase in the prevalence of bilharzia throughout the Senegal River Basin, including Rosso, Lac R'kiz area, Richard Toll, and Lac de Guiers (Jobin 1999). In all Mauritanian villages around Lac R'kiz that were visited during this study (Gouelit, Nasra, Keke 1 and Gani), the people reported an increase in waterborne diseases after completion of the Diama dam.

2. **Pest control**. Maintaining flood dynamics is important for controlling the spread of invasive plants such as Cattail (*Typha australis*), Water primrose, Azolla sp., Kariba weed, Water hyacinth etc. Vast areas in the Senegal Delta are covered by Typha including parts of the Laouvaja inlet. These Typha fields may block water inflow leading to reduced water availaibility and increased stagnancy.

3. **Biodiversity**. The value of the Sahelian wetlands to birds and other wildlife have been stressed many times (Zwarts *et al*. 2009). The biodiversity value of Lac R'kiz is clearly demonstrated by the importance of this site for many migratory birds including thousands of Garganey, Ruff and other species. More information on the waterbirds in Lac R'kiz area can be found in appendix 2. Populations of most large mammals have probably been extirpated, although Warthogs were seen during the field visit and a dead African civet (*Civettictis civetta*) was found on the tarmac road south of Lac R'kiz.

4.3 Economic valuation

A separate field mission was conducted by professor Abdoulaye Seck (Cheikh Anta Diop University, Dakar) in June 2015 in order to carry out an economic valuation of the relevant benefits. In total 416 households were interviewed in six villages in the area around Lac R'kiz: Gaani, Douze-Douze, Gouelit, Keke 1 and 2 and Madina Salam. The study by Prof. Seck is described in a separate report (Seck 2015) but the main results are briefly summarized below.

Vegetable crops
In terms of production, onions and tomatoes are by far the most productive vegetable crops with reported yields of over 10 ton/ha. Most other crops have far lower yields, although the

revenue per hectare may be higher (see table 4.1). The mean production for vegetables is around 5 tons/ha with an estimated value of around €2,000/ha. This is quite similar for rice (see below). Note that these production figures are substantially lower than the data given in the SDAGE, in which an average yield of around 24 tons/ha for vegetables is given (OMVS 2011, p. 63). Crops with the highest revenues are chilli pepper, tomatoes, sweet potatoes and onions (all > €1,000 / ha). Most of the harvest is sold; relatively small amounts are used for own consumption (onions 7%, tomatoes 6%).

Table 4.1 Data on production (in 1000 kg) and revenue per hectare for different agricultural crops around Lac R'kiz, as reported by villagers in the economic valuation study (Seck 2015). Costs in FCFA and Euro are based on the costs in Ouguiyas and may vary according to current exchange rates.

	Production/ha	**Ouguiya**	**FCFA**	**Euro**
Onions	10,9	821992	1639783	2501
Tomatoes	9,9	1238656	2470982	3769
Chilli pepper	8,1	2205943	4400613	6712
Rice	6,1	651041	1298756	1981
Cabbage	4,0	179909	358898	547
Aubergine	2,6	224471	447795	683
Squash	2,4	13763	27455	42
Bissap (*Hibiscus*)	1,8	16750	33414	51
Sweet potatoes	1,3	763187	1522473	2322
Mean: vegetables	5,1	683084	1362677	2078

Rice farming

Potential rice yields in irrigated systems in the Sahel can reach up to 10 tons/ha under optimal conditions (Dingkuhn & Sow 1997). However, actual yields are often substantially lower (4-6 ton/ha) and strongly dependent on the growing season, the distance to the mouth of the river, and crop management practices (Haefele *et al*. 2001). Seck (2015) found an average yield of 6.1 tons/ha in several villages around Lac R'kiz, giving an estimated monetary value of roughly €2,000/ha (table 4.1). Average yields in the village of Gaani were reported to be between 6–9 tons/ha; villagers in Gouelit reported yields of roughly 7 tons/ha before the dams compared to 3–4 tons/ha in the current situation. Based on a study among 42 farmers located between Keur Macène and Podor, average rice yields of 4.4 tons/ha were reported by Haefele *et al*. (2001). On the Senegalese side of the Valley, average rice yields are reported to amount to roughly 5–6 tons/ha (USAID 2009). The consumption of water by rice farming is between 15,000 – 20,000 m^3 per ha, depending on the season (OMVS 2011). Roughly three-quarters of the rice harvest is sold at markets and one quarter is used for own consumption (Seck 2015).

Fishing

Average fish harvests are estimated at 5–10 kg/fisherman/day (Seck 2015). This is substantially higher than the 1-2 kg estimated by the OMVS (2010). The revenue is estimated at around 4-5 euro per kg. The most important period for fishing is September–December. Based on an average daily harvest of 7.5 kg/ fisherman, roughly 1 kg is for auto-consumption and 6.5 kg is sold at markets at Rosso, Gaya, Dagana and Richard Toll (OMVS 2010).

Figure 4.9: fish (unknown species) caught at the Laouvaja inlet near the village of Gouelit.

Livestock

Potential stocking rates for livestock depend on the quality and quantity of the grass sward. In the arid environment of the Sahel, grass biomass is very low and large areas are needed to provide enough food for livestock. Because of the arid environment, stocking rates are probably low. The average size of a single herd is around 25 animals (Seck 2015). Although the animals are used for the consumption of meat and milk, these products are not regularly sold at markets (Seck 2015). The direct contribution of livestock to the household income is therefore low compared to other forms of land use.

4.4 Summary

Water availability is the core driver of ecosystem services in Lac R'kiz and environs. The lake is situated in a region characterized by low and erratic rainfall patterns. Land use and the livelihoods of local people around the lake and its inlets depend fully on this ecosystem service. Water availability in Lac R'kiz itself has diminished in the last decades and most open water is now concentrated in the Laouvaja inlet. In addition, many of the services or benefits including water quality and disease control depend on the seasonal variation in flood dynamics and may hence become threatened by increased stagnancy of the water. Water levels and consequently the inflow of water are controlled indirectly by the upstream water management at Manantali. In addition, the inflow of water may also be hampered by Thypha infestation in the inlets.

The arid conditions in which Lac R'kiz is situated mean that rain-fed agriculture is not feasible, making the system entirely dependent on water inflow through the inlets. During dry years, the lake itself will largely dry out. Possibilities for irrigated agriculture are limited and small-scale vegetable gardening is restricted to a small strip around the Laouvaja. Land use in this area is thus very sensitive to fluctuations in water availability, reduced water quality due to increased stagnancy, and reduced inflow caused e.g. by the spread of *Typha* in the inlets. An overview of the ecosystem services, benefits, locations, economic values and associated risks and constraints are given in table 4.2 and 4.3.

Future water availability and resilience

The future water availability in Lac R'kiz and its inlets hinges on active water management of the Senegal River. From this perspective the operational management of Manantali and Diama are most important (artificial flood regime). Flooding during the wet season and at least partially a dynamic water regime are key players in defining the ecosystem services. This is not only important to avoid Typha infestation but also for fish communities in the lake or inlets.

Several villages are located around Lac R'kiz and the livelihoods of at least >5000 people depend on the availability of water. Their resilience is under pressure from water scarcity and future developments such as climate change. Some important opportunities to strengthen their resilience and / or to restore the wetland functions are:

- Removal of Typha stands (and organic matter) in the inlets to Lake Rkiz. This will facilitate the inflow of water from the Senegal river and stimulate fish production;
- Investigate the opportunities for rehabilitation of former rice cultivations in the Lac R'kiz area;
- Maintenance of flood dynamics in water management;
- Design and develop fish breeding places (e.g. the banks of the inlets) as well as locations to stock larger fish for future reproduction. For this it is important to set up local communication process with stakeholders.

Tabel 4.2 Overview of provisioning services around Lac R'kiz.

Group	**Benefits**	**Actual use**	**Location**	**Economic value**	**Constraints and risks**
Biomass	Cultivated crops	Small to medium scale vegetable gardening: mainly onions, cabbage, tomatoes, chili pepper, aubergine, carrots etc.	Directly around villages (mainly west side of the lake), within 300m of the lake	Onions, tomatoes, chilli pepper, sweet potatoes: > €2,000 / ha Cabbage, aubergine etc: €500 – 700 / ha	• Water shortage due to annual fluctuations in rainfall, overall decrease in precipitation, inlet channel being blocked by Typha reedbeds, upstream developments • Dependence on recession agriculture in some villages • Location restricted to area directly around the lake • Animals feeding on crops
	Agriculture	Rice farming	Large-scale (foreign) rice project NW of lake; main rice areas located area directly north (<10 km) of Senegal River	€2,000 / ha	• Water shortage due to annual fluctuations in rainfall, overall decrease in precipitation, inlet channel being blocked by Typha reedbeds, upstream developments
	Livestock	Small numbers of goats, sheep and cattle	Sedentary livestock directly around the villages; transhumant Peulh in the wider area	Sheep, goats: <€100 Cattle, camels: >€500	• Water shortage • Food (grass) availability and quality
	Wild animals	Fishing	Now restricted to Gouelit village; also villages along the Senegal River such as Gaani	< €5 / kg	• Water shortage (see above) • A reported decrease in water quality • A reported decrease in fish diversity and size
	Woodland	Use for timber and small-scale use (e.g. charcoal)	Borders of the lake and environs	Local use	• Droughts, but increased rainfall during last decades (since 1994) is positive
Water	Drinking water	Drinking water for people and livestock	12 villages around the lake (all west side?) with an estimated population of around 1000 people; sedentary livestock around villages; transhumance by Peulh around entire lake area	€2 per person per month	• Water shortage (see above) • A reported decrease in water quality • Increase in diseases e.g. bilharzia, malaria, dysentery etc in human population • Decreasing condition of cattle and seemingly high mortality

Tabel 4.3 Overview of selected regulating services around Lac R'kiz.

Group	Class	Actual use	Location	Constraints and risks
Disease control	Waterborne diseases (human)	Disease control through supply of fresh water for drinking	12 villages around the lake (all west side?) with an estimated population of around 1000 people	• A reported decrease in water quality • Increase in diseases e.g. bilharzia, malaria, dysentery etc in human population
	Waterborne diseases (livestock)	Disease control through supply of fresh water for drinking	Sedentary livestock around villages; transhumance by Peulh around entire lake area	• A reported decrease in water quality • Decreasing condition of cattle and seemingly high mortality
Pest control	Invasive species	Pest control through natural hydrological cycle	Open water, mostly where stagnant	• Expansion of Typha reedbeds due to changes in hydrology • Expansion of e.g. Water primrose, Azolla sp., Kariba weed, Water hyacinth etc. • Expansion of invasive species (see above) may lead to blockage of water bodies, increased stagnancy, presence of parasites such as bilharzia, and negative impacts on local biodiversity
Ecosystem health	Biodiversity	Species diversity, habitat availability etc through presence of water in arid landscape	Open water, lake shores, area around lake, inlet channel	• Decrease in water quantity and quantity (see above) • Invasive species (see above) • Increased hunting pressure during dry years???


RIZ
DE LA VALLEE
50KG

5 Lac de Guiers

5.1 Characterization and hydrological context

Lac de Guiers is a shallow lake south of the Senegal River, located roughly 17 km southwest of Richard Toll (figure 5.1). The lake measures roughly 30–50 × 6 km and is being fed primarily by the Taoué canal, a 17 km long canal that connects the lake with the Senegal River. Other sources of water such as rainfall contribute very little to the water volume in the lake (OMVS 2013).

Holding a volume of roughly 500 million cubic meters of water, Lac de Guiers is the most important source of drinking water for Dakar. Currently around 60% of the capital's drinking water is extracted from the lake (Mbaye 2013, Diop *et al*. 2016). Water treatment plants at Ngnith and Keur Momam Sarr currently provide around 180,000 cubic meters of water a day to Dakar (Alam & Dione 2004, WWF 2011). Because of the strategic and economic importance of the water management in the hydrological system of Lac de Guiers, a local water authority (Office du Lac de Guiers, OLAG) was extablished in 2010 that should ensure sustainable water management and restauration of ecosystems (Bos *et al*. 2015). Besides the drinking water for Dakar, water from the lake is used for irrigated agriculture (mostly sugar cane) and a significant part is lost by evaporation (Gac & Cogels 1986).

In some aspects Lac de Guiers is the ecological equivalent of Lac R'kiz: an isolated, shallow lake which is connected to the Senegal River by the Taoué, the only source of water feeding the lake. Similar to Lac R'kiz, Lac de Guiers has been subject to major changes in the hydrology of the area due to upstream developments and the impacts from changing rainfall patterns. However, in contrast to the natural Laouvaja and Sokam inlets that are feeding Lac R'kiz, the Taoué is an artificial canal that is actively managed, for example by removing *Typha* along its banks (figure 5.4). In addition, large-scale industrial agriculture has been developed in the area between Lac de Guiers and Richard Toll, most notably the vast sugar cane plantations run by the *Compagnie Sucrière Sénégalaise* (CSS).

Reconstruction of the past

Lac de Guiers functioned as a natural system up to 1916, when a dike was built near the Taoué wetlands in order to prevent incoming seawater (Cogels *et al*. 1994). In 1947, a dam was constructed in the Taoué river to keep fresh water inside the lake and river for irrigation purposes. In 1956 the Keur Momar Sarr dike was built at the southern tip of the lake which isolated the lake from the Ferlo valley; however the connection with the Ferlo valley was re-established in 1988. In order to meet growing demands for irrigation water for the sugar cane industry, the Taoué canal was made in 1974 which has taken over the function of the original Taoué river (Gueye 1999). In 1980 a second dam was made in the Taoué canal. The most prominent developments however have been the construction of the Diama and Manantali dams in the 1980s.

Before the 1980s (*avant-barrages*), the volume of the lake was subject to large fluctuations, from 50–70 m^3 at the end of the dry season to 500–600 m^3 during the flood season (Michel 1973, Varis & Fraboulet-Jussila 2002). The maximum surface area of the lake was roughly 300 km^2 (Gac & Cogels 1986).

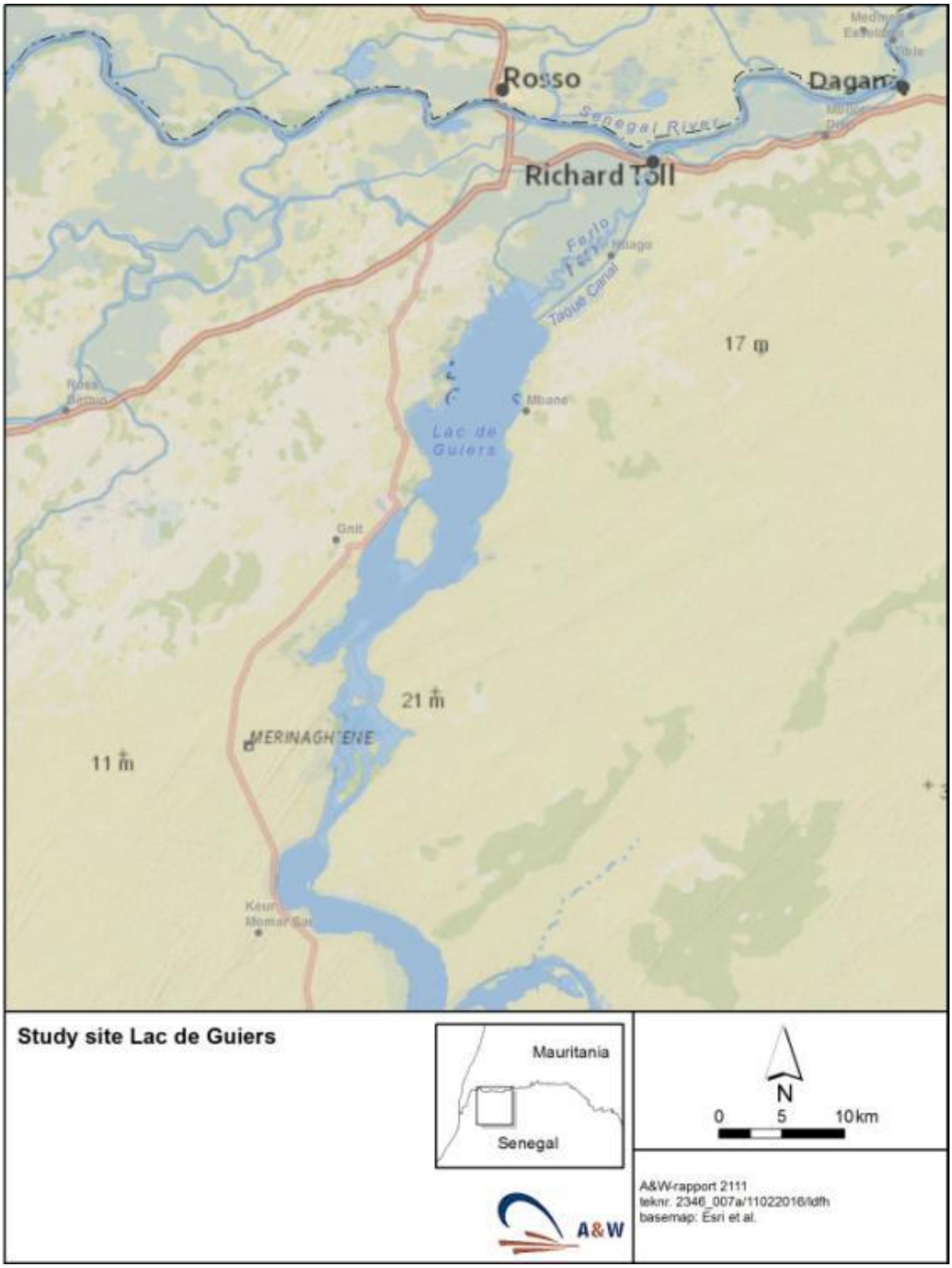


Figure 5.1 Location of Lac de Guiers and the Taoué canal.

Figure 5.2 shows the considerable fluctuations in the water levels, with differences between wet and dry season levels of over 2m (Cogels et al. 1994). The peak levels were usually attained in October–November. The impact of the Diama dam on water levels in Lac de Guiers is clearly visible: from 1985 onwards, mean water levels have increased, the annual variation has decreased, and the peak levels have stabilized. The annual fluctuations have decreased even more since the early 1990s, due to changing water management at the second dam in the Taoué. As is illustrated in figure 5.3, water levels since the mid-1990s been kept extremely stable at around 2 m.a.s.l. and the annual variation has been reduced to no more than a few decimeters (Arfi *et al*. 2003). In addition to the impacts on water levels, the construction of the Diama dam has significantly reduced the salinity of the lake, since salt sea water can no longer flow upstream in the dry season (Varis & Fraboulet-Jussila 2002).

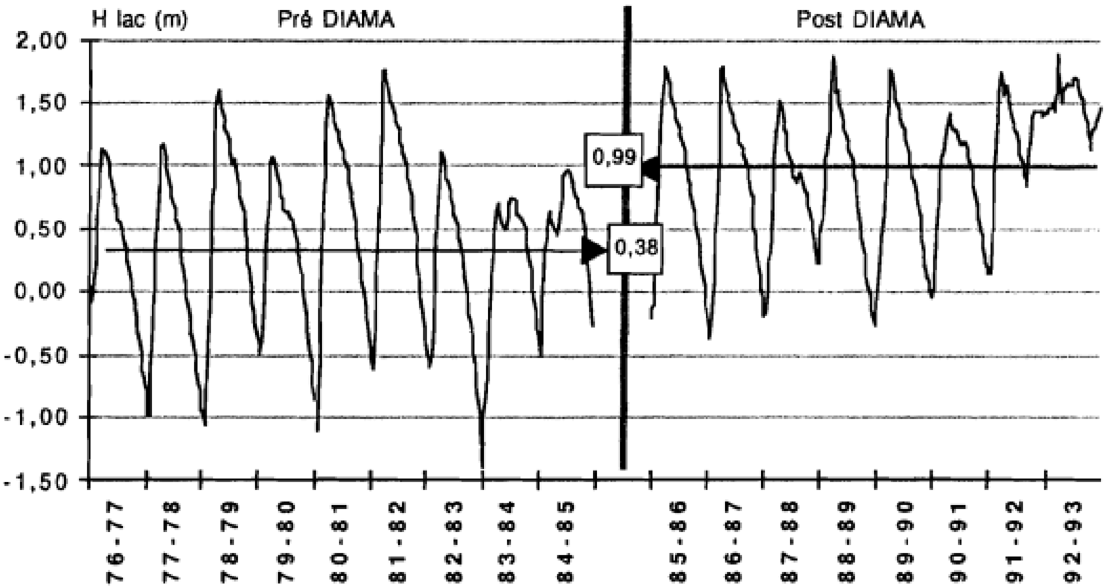


Figure 5.2 Water level fluctuations in Lac de Guiers in the periods before and after construction of the Diama dam. Source: Cogels et al. 1994.

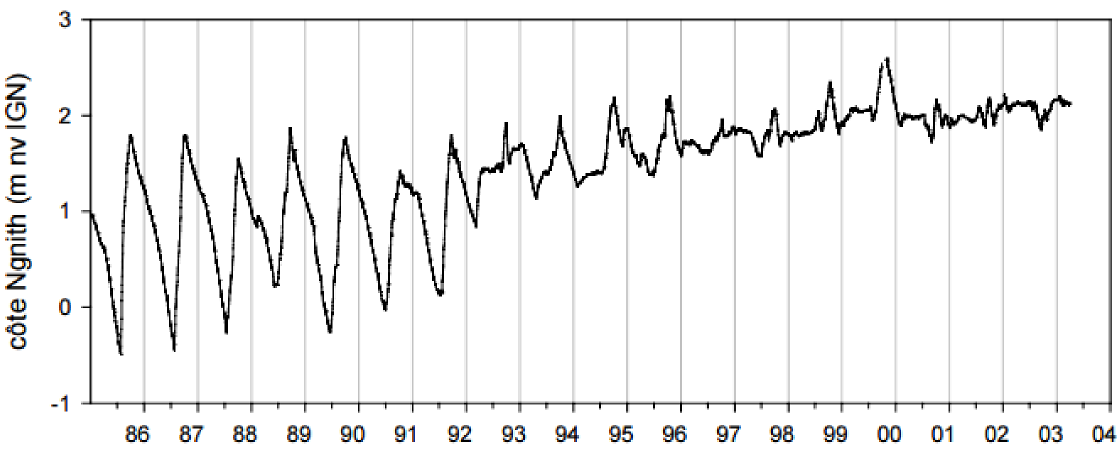


Figure 5.3 Water level fluctuations in Lac de Guiers since the construction of the Diama dam. Source: Arfi et al. 2003.

Figure 5.4 Typha removal from the Taoué canal.

Present water levels and flooding

Water availability in Lac de Guiers has been calculated from Landsat satellite images, using the Automated Water Extraction Index from Feyisa *et al*. (2014; see chapter 2). Figure 5.5 shows the average surface area (ha) of water in Lac de Guiers in the months of October and November for the years 2000–2014. The lake normally is at its largest in these months. The total area of water (maximum lake area) since 2000 appears to be relatively stable. The mean lake area in October is 23,320 ha (SD = 2,631) and in November 23,992 ha (SD = 1,509). It should be noted that these data have not been corrected for the extent of Typha in the lake.

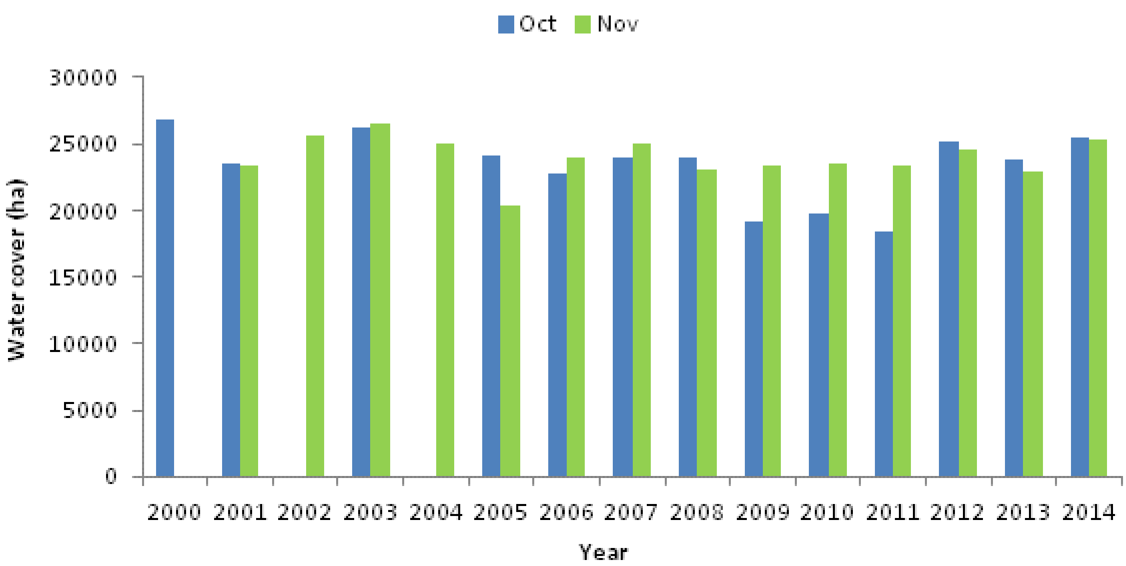


Figure 5.5: Maximum water cover (ha) in Lac de Guiers in the months of October and November.

Current land use and habitats

An overview of the habitats and land use in the Senegal Delta, including the area around Lac de Guiers, is given by Zwarts *et al*. (2009). The corresponding map is shown in figure 5.6. The area north of the lake is predominantly used for agriculture such as sugar cane and small-scale rice and vegetable fields (see the next sections for more details). The dry Sahelian habitats around these areas are vegetated by *Balanites aegyptiaca*, *Acacia tortilis* and *Prosopis juliflora*.

As can be seen in figure 5.6, large parts of the northwestern and northeastern shores of the lake are covered by dense *Typha* fields. The proliferation of *Typha* has been triggered by the relatively stable water levels since the construction of the Manantali and Diama dams in the 1980s, and the reduced salinity levels (see Varis & Fraboulet-Jussila 2002).

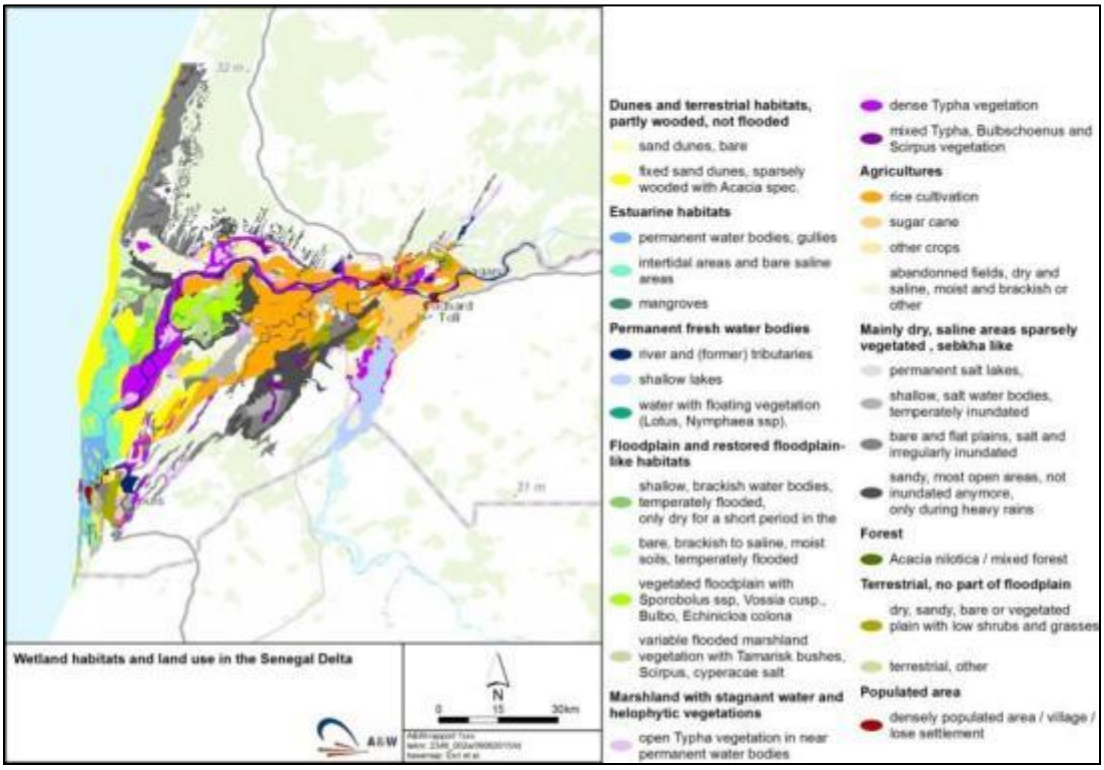


Figure 4.2: Habitats and land use in the Senegal Delta. Source: Zwarts et al. (2009).

5.2 Ecosystem services

Provisioning services

The ecosystem services in the area around Lac de Guiers have not been studied in detail for this pilot study, but some generalities can be given based on the field visit and information from the literature:

1. **Sugar cane**. The most prominent form of land use is the vast area of sugar cane north of the lake, which has been made possible by the proximity of the Senegal River with a guaranteed water supply. In 1971 the *Compagnie Sucrière Sénégalaise* (CSS) was established in the area. Since then, some 10,000 ha of irrigated sugar cane fields have been developed in the area around Richard Toll, with an annual production of over 1,3

million tons of sugar cane from which over 100,000 tons of sugar are produced. Sugar cane has a high water consumption with roughly 38,500 m^3 per ha per year (OMVS 2011). The large-scale cultivation of sugar cane is the best example of industrialized ecosystem services in the area facilitated by water from the Senegal River.

2. **Local agriculture**. Rice paddies and small-scale vegetable fields (mainly onions, cabbage, tomatoes) are located in a few small strips of land around the sugar cane fields. The main rice-growing area is located northwest of the lake, bordered by the N2 to the west and the sugar cane fields to the east. Vegetables such as onions and cabbage are mostly grown in small strips of land next, for example besides the N2 or between the northern shores of the lake (that are covered by *Typha*) and the southern parts of the sugar cane fields. Some larger vegetable fields are located near the village of Ntiago, close to the Taoué canal some 8 km northeast of the lake.

3. **Fishing**. In the past, fish harvests from the lake have been estimated at around 1,600 tons/year (Gac & Cogels 1986). The construction of the Diama and Manantali dams have changed the ecological conditions (stabilized water levels, reduced salinity) for fish in the lake, as well as the conditions to fishermen. An important example concerns the spread of Typha, which may provide nursery grounds for the fish but at the same time hamper access to fishermen (Magrin & Seck 2009). As also observed at Lac R'kiz, fishing as a livelihood is often combined with other sources of food and income such as agriculture.

4. **Livestock**. Similar to Lac R'kiz, the lake provides drinking water and grazing grounds to cattle from Peulh pastoralists. However, much of the land around the northern parts of lake are occupied by agriculture and access to the lake has become increasingly difficult (Mar & Magrin 2008).

Regulating services

The regulating services mentioned for Lac R'kiz are likely to be important for Lac de Guiers too: disease control, controlling the spread of invasive plants like Typha, and maintenance of biodiversity. These services have been affected by the flood regime *après-barrages*. The relatively stable water levels since the construction of the Manantali dam, and the reduced salinity levels caused by the Diama dam have resulted in the proliferation of Typha, which now covers large parts of the northwestern and northeastern shores of the lake (figure 5.6; Hellsten *et al*. 1999, Varis & Fraboulet-Jussila 2002).

5.3 Summary

Similar to other parts of the Senegal River Basin, the area around Lac de Guiers has been subject to major environmental and social changes related to the availaibility of water. These changes are caused by e.g. altered precipitation patterns, the construction of the Diama and Manantali dams, the consequent stabilization of water levels in Lac de Guiers, expanding agriculture and irrigation, overgrazing etc. (Varis *et al*. 2006). Many hydrological developments have taken place around Lac de Guiers, including the construction of the Taoué canal with two dams to guarantee water supply for irrigation purposes. These developments have made Lac de Guiers much more a controlled system than Lac R'kiz.

Ecosystem services around Lac de Guiers are in principle not very different from those at Lac R’kiz, although the guaranteed supply of water from the Senegal River through the artificial Taoué canal has made possible the large-scale development of industrial sugar cane production, as well as the cultivation of rice and vegetables on a smaller scale. The relatively constant high water levels in Lac de Guiers are a sharp contrast to Lac R’kiz where water availability is far from guaranteed.

Table 5.1: Provisioning services in the area around Lac de Guiers.

Group	Class	Actual use	Location
Biomass	Agriculture	Large scale sugar cane plantations	Richard Toll area south to Lac de Guiers
		Rice farming	Mainly south of Keur Dimba Diallo, between N2 and sugar cane fields
	Cultivated crops	Small to medium scale vegetable gardening: mainly onions, cabbage, tomatoes, chili pepper, etc.	Small to medium sized areas around the sugar cane fields, some larger plots near Ntiago
	Livestock	Small numbers of donkeys, goats, sheep and cattle	Probably transhumant Peulh in the wider area
	Wild animals	Unknown	Unknown
Water	Drinking water	Drinking water for people and livestock	Taoué canal and Lac de Guiers

6 Middle Valley

6.1 Characterization and hydrological context

The vast alluvial plain between the Senegal Delta in the west and Bakel (where the Falémé tributary joins the Senegal River) in the east, is known as the 'Middle Valley'. The middle valley is roughly 400 km long and up to 25 km wide. This vast area is reflected in the geographical variation in rainfall, ranging from 500 mm in the upper parts (near the border with Mali) to less than 250 mm in the lower parts. The latter area has been visited for this pilot study. The study site consists of the area around Ndioum, around 110 km east of Richard Toll, in particular the village of Thielao (figure 6.1). This site is considered representative for the landscape and ecosystem services of the Sahelian part of the Middle Valley.

The Middle Valley is situated in a similar arid environment as Lac R'kiz and Lac de Guiers, but in contrast to these study sites, the Middle Valley is centered around the Senegal River itself rather than being linked to the river by an inlet or canal. This means that problems relating to water scarcity, Typha infestation, water quality or diseases propagated by stagnant water are much less prominent compared to the situation at Lac R'kiz and Lac de Guiers.

The altered water regime after construction of the Manantali and Diama dams has had some important implications for agriculture in the area. Most importantly, the goal to increase rice self-sufficiency has caused a shift from traditional recession agriculture to actively irrigated rice production throughout the Senegal River Valley. Rain-fed rice production, which is more common in wetter regions such as the Casamance in southern Senegal, is obviously absent in this arid region. The cultivation of sorghum on the floodplains was characterised by low yields (less than one tonne/ha) but also demanded little labour and hardly any financial investment (Fraval *et al*. 2002, Kitissou *et al*. 2007). In contrast, irrigated rice farming is much more productive (4-6 tons/ha, occasionally higher) but requires high labour input, organization and substantial financial investment (e.g. for fertilizer, fuel, pumps, maintenance etc).

Reconstruction of the past

The natural flood cycle *avant-barrages* inundated vast areas of the Middle Valley's floodplains. Before the 1970s, over 300,000 hectares were flooded annually on both sides of the Senegal River of which over 100,000 ha was cultivated (Adams 19xx). Although good-quality satellite images for that period are not available, the maximum flood extent in the study area has been visualized in figure 6.2 which is used as a proxy for years with good rainfall and flooding. This map shows the flood extent during the flood peak in October 2013. It is evident that large areas around the Senegal River and its side-arms Gayo and Doué are inundated, providing opportunities for large areas of recession agriculture. In contrast, at the end of the dry season (June 2015) hardly any water can be found outside the main watercourses.

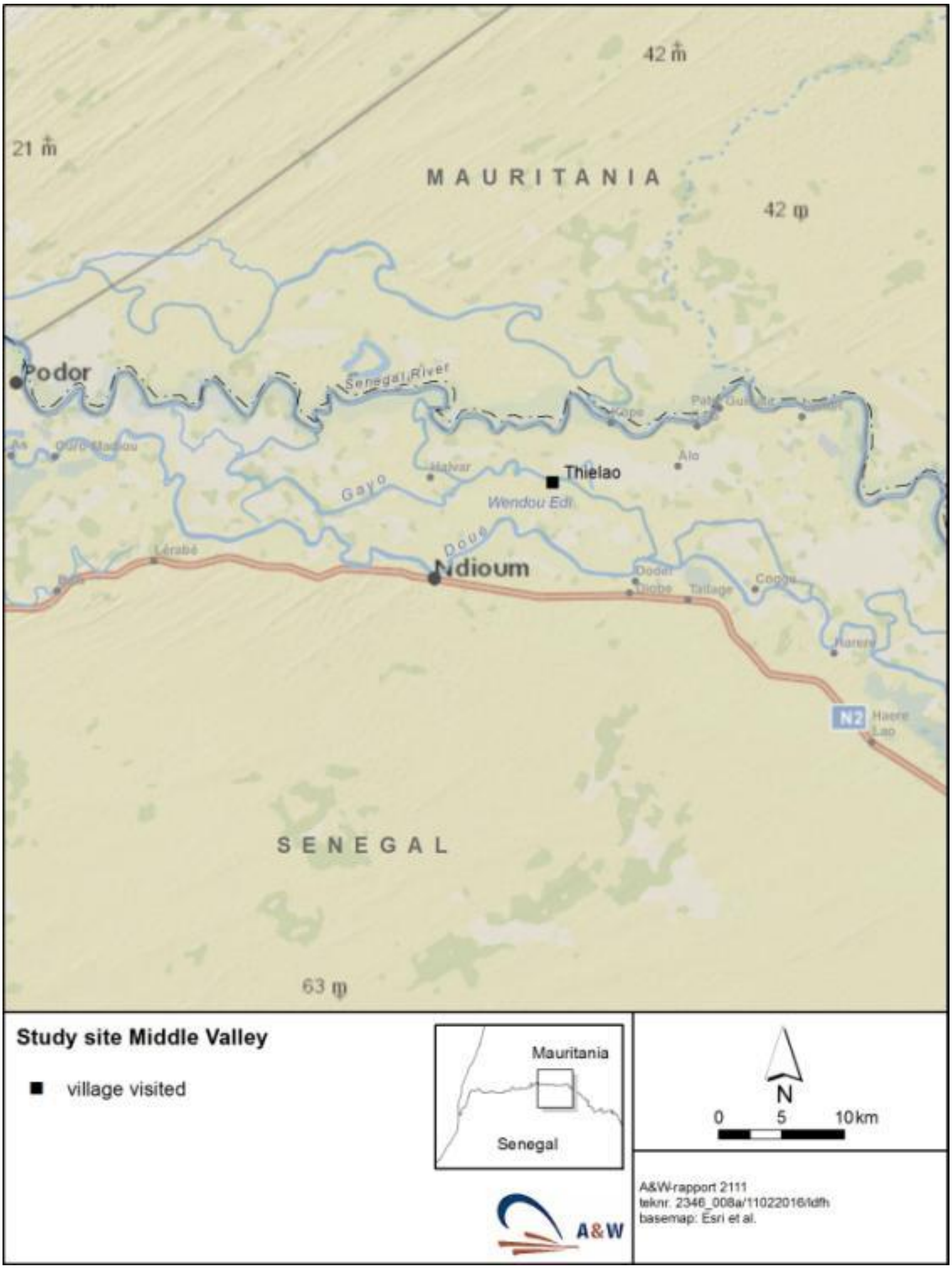


Figure 6.1. Location of the study sites in the Middle Valley.

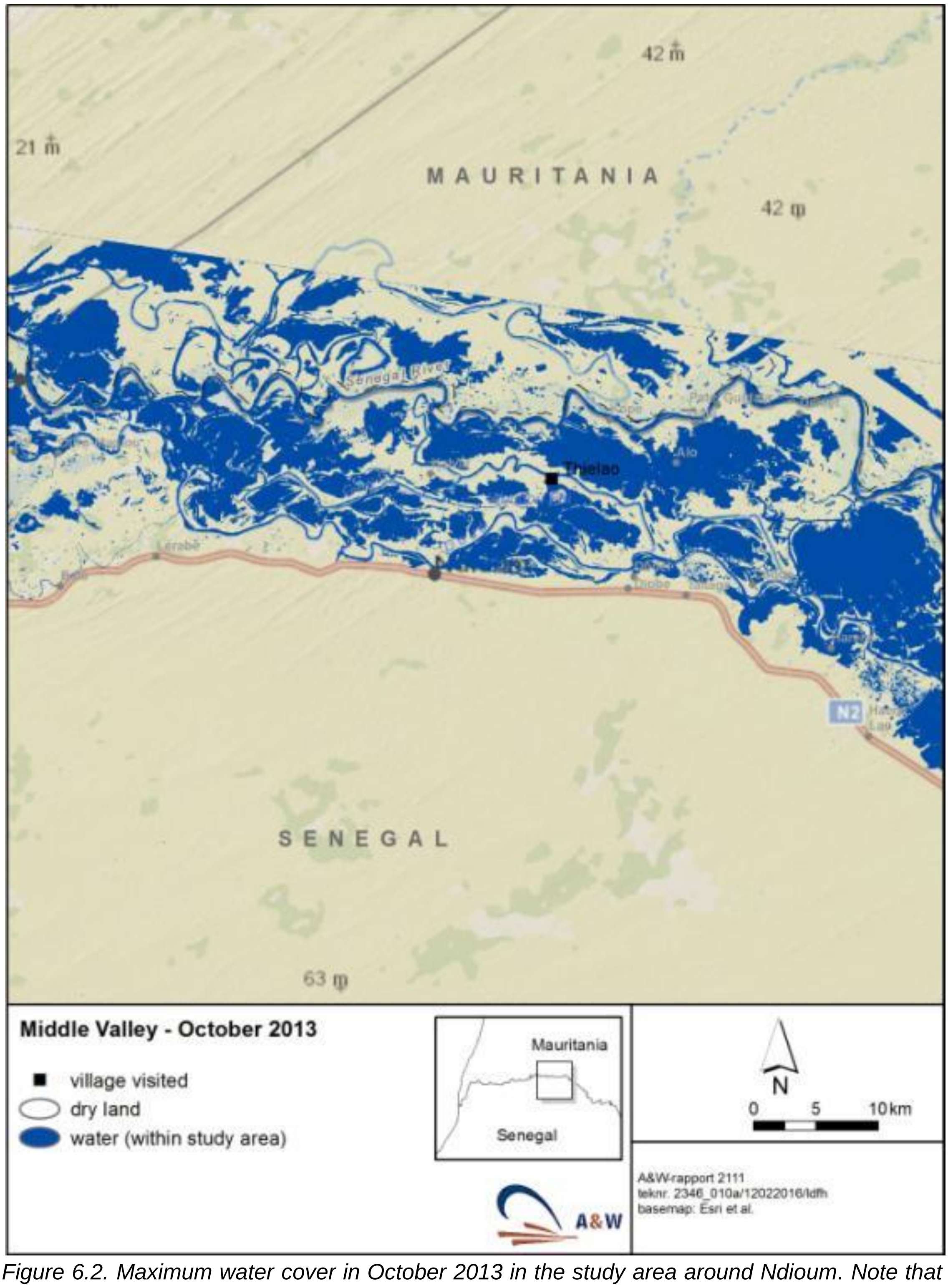


Figure 6.2. Maximum water cover in October 2013 in the study area around Ndioum. Note that the northern part of the valley is off the satellite image and hence not displayed on this water map.

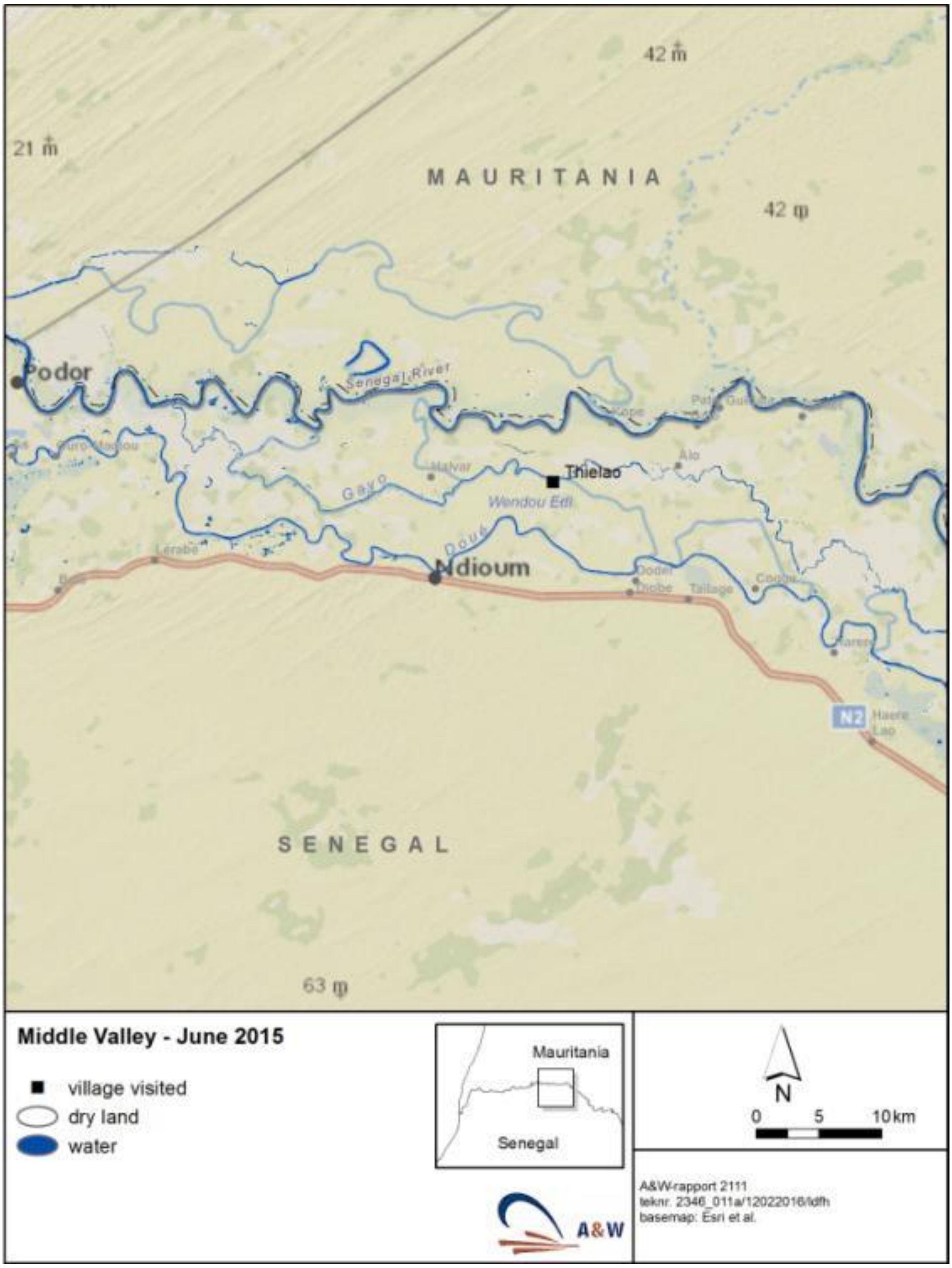


Figure 6.3. Maximum water cover at the end of the dry season, in June 2015 in the study area around Ndioum.

Present water levels and flooding

The seasonal variation in water cover in the Middle Valley is shown in figure 6.4. These data refer to maximum water cover (flooded area) per month as calculated by the AWEI index (Feyisa *et al*. 2014), averaged over the years 2007–2015. The areas illustrated in figure 6.4 refer to the northern part of the Middle Valley (the 200 km stretch roughly between Dagana and Galoya) and the middle part (roughly between Galoya and Bakel). These two areas of the Middle Valley show a combined maximum flooded area of around 260,000 ha (2,600 km^2), although these values are rough approximations. However, these patterns seem to match the historical flooded area reported in the literature (e.g. Adams 19xx). As can also be seen in figure 6.4, the peak in water cover in the northern part takes place roughly one month later (October) than in the middle part of the valley (September).

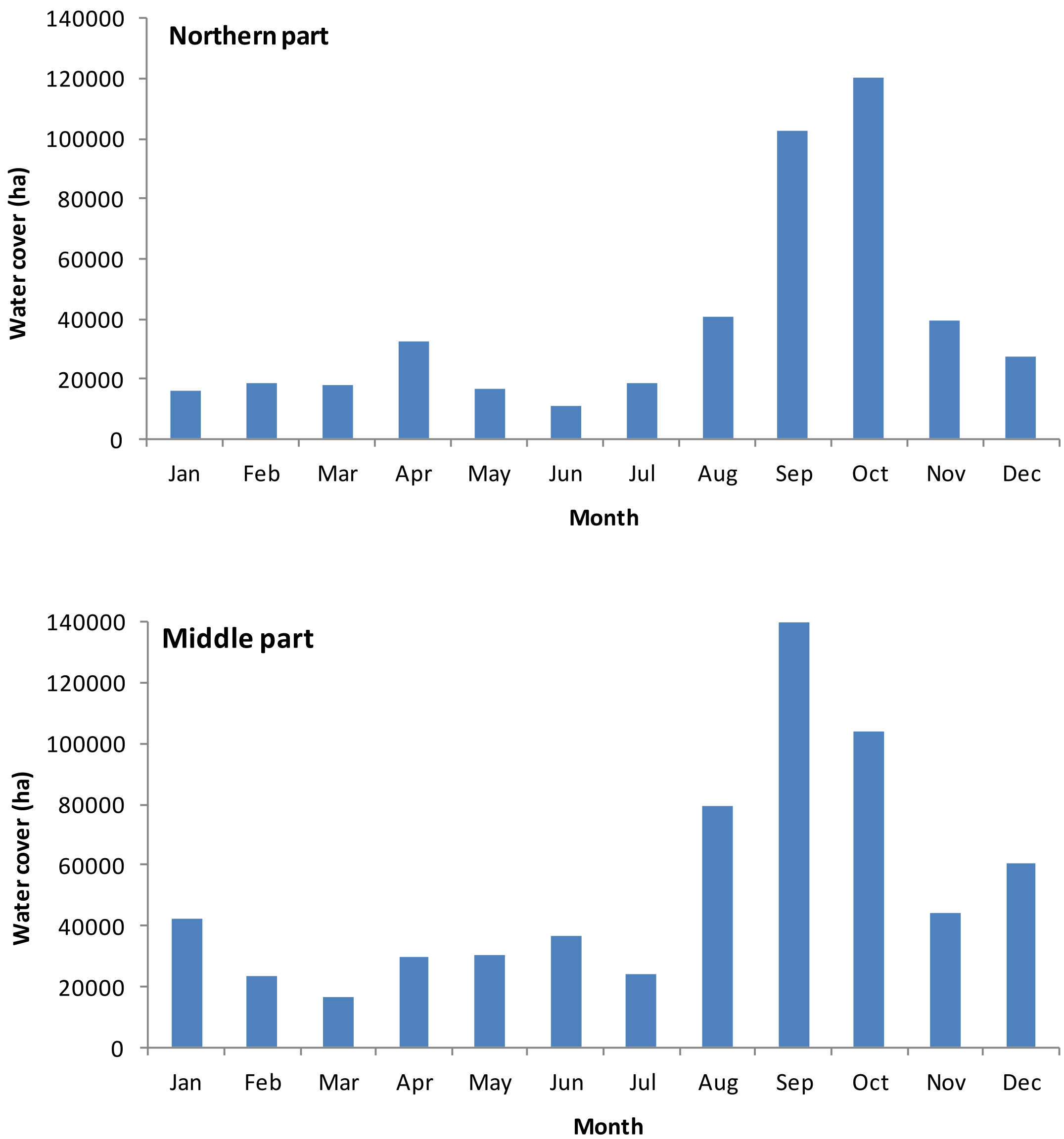


Figure 6.4. Seasonal variation in maximum water cover in the Middle Valley. Top: northern part (roughly Dagana – Galoya), bottom: middle part (roughly Galoya – Bakel).

Current land use and habitats

The area is characterised by arid Sahelian ecosystems, including semi-desert and thorn scrub. The woody vegetation is dominated by *Balanites aegyptiaca* and *Acacia spp.* Immediately south of Thielao is a small wetland that has a narrow strip of *Acacia nilotica* flood forest. There are three Classified Forests around Ndioum (Forêt de Thielao, Forêt de Oualo and Forêt de Diara), although the term 'forest' is perhaps somewhat optimistic. Besides the Senegal River, there is year-round water supply in two side-arms (Gayo and Doué) that run south of the river.

An analysis of the land use in the middle valley is given by Wester *et al*. (1995). Due to the arid environment, the potential for rain-fed agriculture is very limited. Traditionally, sorghum and beans were grown in the low-lying areas (*cuvettes*) that are flooded by the river in years with sufficient rainfall. This flood-recession agriculture has been largely replaced by irrigated rice production in the form of village irrigation schemes (*Périmetres Irriguès Villageois; PIV*) and later by private irrigation schemes. A PIV covers about 20 ha and is divided into plots of 0.1 to 0.4 ha for each family. Irrigation is done by pumps that are running on diesel engines. The production of these PIV's is roughly 3–6 ton/ha (data from Wester *et al*. 1995).

In the study area, the major rice fields are located north of Ndioum (figure 6.5). This map shows the areas of open water as well as the moist vegetated areas in and around the study area. These vegetated areas can refer to irrigated rice fields as well as natural wetlands, such as Wendou Edi south of Thielao.

6.2 Ecosystem services

The interviews held at the village of Thielao confirm the changes in land use discussed above. Rice farming is currently the most important livelihood activity here, followed by fishing and vegetable farming. Sorghum is no longer cultivated. The average rice production is estimated at 4 tons/ha, which is used for subsistence and to generate income by selling rice on the markets. Fishing is mainly done in the Gayo River; fishing in the small wetland (Wendou Edi) is considered to be no longer profitable. The area around the wetland is now mainly used as grazing ground for livestock (cattle and goats). Vegetable farming consists mainly of onions, cabbage, okra, aubergine and chili pepper.

Although the climatic conditions in the middle valley are comparable to Lac R'kiz, the year-round availability of water in the Senegal River and its side-arms Gayo and Doué provide a sharp contrast with the lake. In addition, no problems with *Typha* or a decrease in water quality are reported by the villagers in Thielao.

The small wetland (Wendou Edi) immediately south of Thielao harbours some valuable regulating services, in this case related to biodiversity and habitat, in the form of a small strip of *Acacia nilotica* flood forest (figure 6.6). This habitat has become very rare in Western Africa (Zwarts *et al*. 2009).

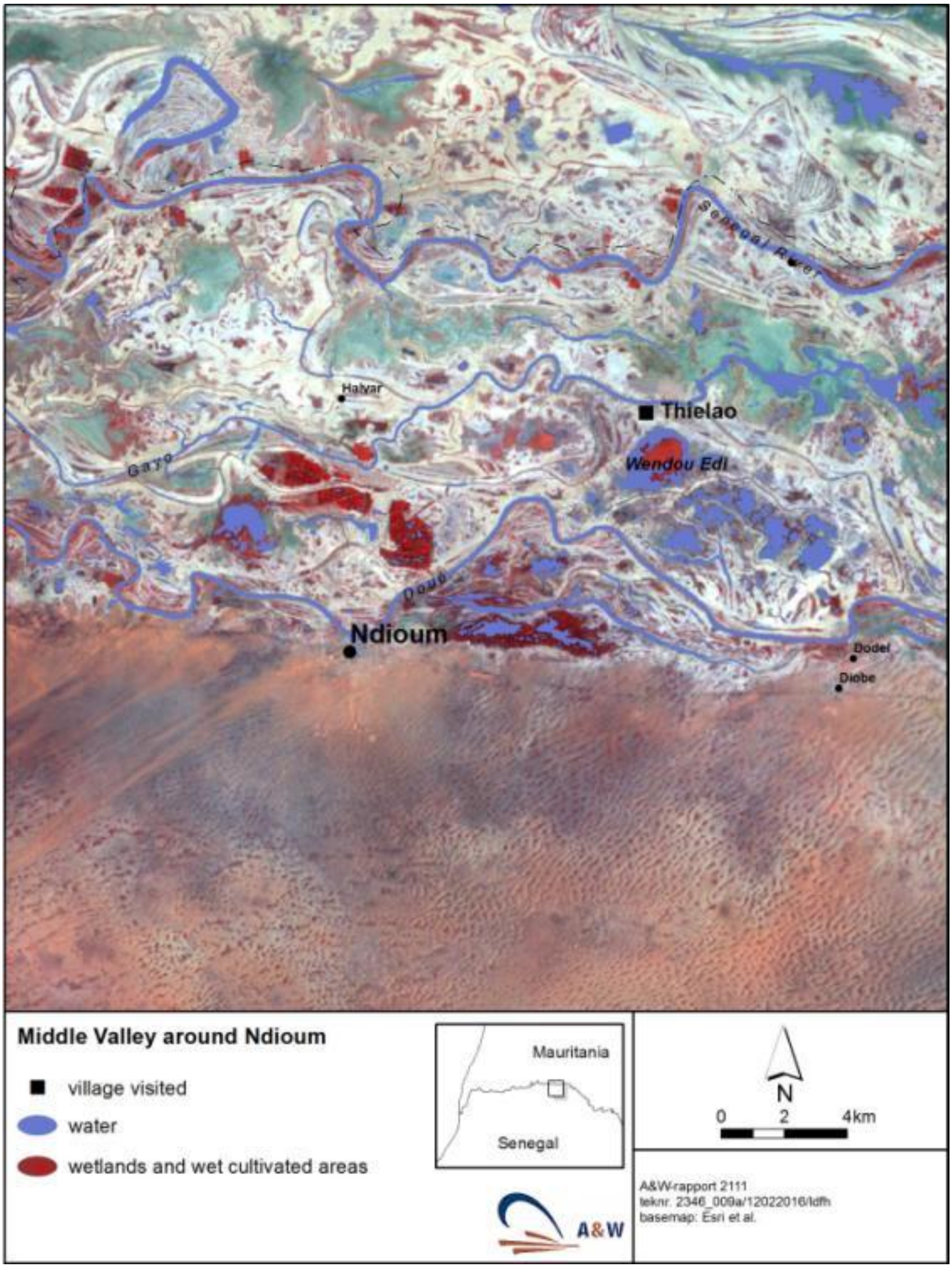


Figure 6.5. Indication of water cover and moist depressions (wetlands and rice fields) in the study area. The wetland Wendou Edi south of Thielao is clearly visible, as are the rice fields scattered throughout the area. Map based on satellite image from 13 October 2011.

Figure 6.6 Goats and cattle in the small strip of Acacia nilotica forest at Wendou Edi wetland, Thielao.






7 Synthesis

In this chapter we evaluate the results of the assessment that was done in the three pilot areas, and put these in a wider perspective. Furthermore, we elaborate on how the current approach and the corresponding outcomes can be applied efficiently on a basin wide level. To perform a systematic evaluation we follow the questions mentioned in Section 1.3.

7.1 Are ecosystem services an appropriate way to show the benefits of wetlands?

Land use versus ecosystem services

In arid climate zones like the Sahel and northern Sudan savannas – which characterize the northern part of the Senegal River Basin – availability of water is essential for life. Land use and livelihoods of the rural communities in these zones are the result of a centuries long adaptation process to scarce and often unpredictable water resources. In the drier Sahel zones (100-400 mm annual rainfall), these resources are almost solely confined to the major rivers (Senegal, Niger), their tributaries and connected wetlands. From this perspective it is no surprise, that the rural communities rely heavy upon the water resources in the river basin.

The provisioning services of wetlands in the arid zones comprise all forms of land use by these communities. This includes rice production, vegetable farming, fishing and livestock; sugar cane production has been largely industrialized and is restricted to the area around Richard Toll and Lac de Guiers. Irrigated rice production is concentrated in the Senegal River Valley, within 10 km of the Senegal River. Around 1,200 ha of rice fields are situated near Lac R'kiz but the status of these fields is unclear, because of erratic water availability in the lake. The cultivation of vegetables is mostly small-scale but still one of the most important livelihood activities at the village level. Vegetable fields are mainly restricted to small areas around the villages and in close proximity to water sources such as the Senegal River, the Taoué canal or the Laouvaja inlet near Lac R'kiz. Livestock keeping is widespread but often at low densities. To a lesser extent, also the benefits from woodland (timber, beehives, charcoal, medicinal use) and plants (medicinal use) in general should be mentioned.

More to the south, in roughly the Soudan-Guinea savanna zone with an annual rainfall of 400–800 mm), rainfall increases and rural communities are less dependent on water resources generated by the river. Rainfall becomes more important in governing land use and crops are less dependent on active irrigation. In the past, grazing grounds were restricted to within 15 km of rivers, floodplains or temporary ponds; the introduction of man-made watering points has allowed herders to graze their livestock in areas that would otherwise be inaccessible. However, the river and its resources are still of paramount importance for farming rice and vegetables, as source of fish and other products from waterlogged areas. Even more to the south (> 800 mm rainfall), at the higher plateaus in Mali and Guinea, ecosystems and land use are mostly shaped by rainfall and also the use of fire to stimulate grass regrowth for cattle and to clear areas for the cultivation of crops. The ecosystem services generated by the river get a more riverine character, such as access to clean water (potable water, washing, cooking) and fishing. In gallery forests along the water courses, indigenous trees are found which are important for cultural and medicinal services (for instance Birnbaum 2012).

At first sight, the ecosystem services generated by the river may be less obvious. However, apart from crucial services as transport (navigation) and water access, (local) markets are to a large extent supplied with products linked to river-generated ecosystem services: rice, vegetables, fish and other products such as herbs for cultural, medicinal or culinary purposes. On top of that, the example of Lac de Guiers shows the paramount importance of delivering potable water to the metropolis Dakar, constituting an ecosystem service on basin level and pivotal to millions of people living in Senegal's Capital. The Senegal river is also providing potable water to Nouakchot.

Table 7.1: The main provisioning services in the study areas.

Group	Class	Actual use	Constraints and risks
Biomass	Cultivated crops	Small to medium scale vegetable gardening: mainly onions, cabbage, tomatoes, chili pepper, aubergine, carrots etc.	• Water shortage due to annual fluctuations in rainfall, overall decrease in precipitation, inlet channel being blocked by Typha reedbeds, upstream developments • Dependence on recession agriculture in some villages • Usually small scale • Animals feeding on crops
	Agriculture	Rice farming	• Water shortage (see above)
		Sugar cane	• High water demand
	Livestock	Goats, sheep and cattle (both sedentary and transhumant)	• Water shortage (see above) • Low food (grass) quality and biomass
	Wild animals	Fishing	• Water shortage (see above) • A reported decrease in water quality • A reported decrease in fish diversity and size distribution
	Trees	Timber, charcoal, medicinal use	• Degradation of wooded areas • Drought
Water	Drinking water	Potable water for people and livestock. Potable water for Dakar (Lac Guier)!	• Water shortage (see above) • A reported decrease in water quality • Increase in diseases e.g. bilharzia, malaria, dysentery etc in human population • Decreasing condition of cattle and seemingly high mortality

The main provisioning services in the study sites are summarised in table 7.1. The core provisioning services are almost similar to land use categories, and have the advantage that they can be mapped and quantified. Other services are less easy to interpret and quantify. This applies for instance to the regulating services of wetlands and woodlands such as water storage, carbon storage, erosion control, biodiversity, microclimate etc (see Sinare & Gordon 2015). Although these regulating services can be more difficult to assess, the concept of ecosystem services provides a coherent language to capture these benefits to communities. Therefore, we can conclude that ecosystem services are a proper way to express the value and benefits of wetlands to communities in the Senegal River Basin.

Translation into economic benefits

The study of Seck (2015) on the economics of ecosystem services at village level has made it possible to translate the provisioning services into economic values for the local community. This makes the concept of ES very tangible. The results of this analysis is summarised in the chapters 4-6 and detailed information can be found in the separate report of Seck (2015). The economic study yields production data per ha for farming and yield in kg per fisherman for fishing.

The most profitable crops, in terms of monetary yields per ha, are rice and vegetables, typically crops that require a high and constant water supply as well as labour, and are thus confined to areas close to permanent water sources. Grazing and fisheries seem to be less profitable when only looking on monetary yields per ha, however these services are less spatially restricted. In the case of fish, it is difficult to link yields to surface area of water, since the connection with the river is essential as well as the dynamics in flooded area and water depth. Fish is caught where there is a congregation near sluices, weirs and pools that dry out. Fish production is however a direct function of flooded area (Laë & Leveque 1999, Zwarts *et al*. 2005), and the yields per fishermen in the harvest period are fully dependent on that area. In terms of labour efficiency, livestock breeding, fisheries and flood recession cultures demand much lower labour input and (pre-)investments than irrigated rice and vegetables (Figure 7.1).

The altered water regime in the post-dam period has had some important implications for agriculture in the area. Most importantly, the goal to increase rice self-sufficiency has caused a shift from traditional recession agriculture to actively irrigated rice production throughout the Senegal River Valley. The cultivation of sorghum on the floodplains in the Middle Valley was characterised by low yields (less than one ton/ha) but also demanded little labour and hardly any financial investment (Fraval *et al*. 2002, Kitissou *et al*. 2007). In contrast, irrigated rice farming is much more productive (4-6 tons/ha, occasionally higher) but requires high labour input, organization and substantial financial investment.

The economic crux of wetlands to rural communities is, especially in more arid regions, that they support the whole set of land use categories that depend on water, from labour intensive rice and vegetable cultivation to fishing and grazing. In terms of food security these provisioning services are complementary (carbohydrates and vegetables versus animal proteins from fish and cattle). Moreover, in particular the poorer communities rely on those elements of the provisioning services which require low levels of pre-investments. Therefore, wetlands in arid regions constitute an important fundament in the subsistence of these rural communities.

In the economic assessment regulating functions are more difficult to quantify, but they are essential to the proper functioning of the ecosystem. In situations where wetlands have deteriorated, rural communities may leave the area and move to urban concentrations for work and food, as was observed during interviews in the R'kiz area. This will ultimately lead to higher social and economic demands on a regional scale. Therefore, the (socio-)economic support generated by wetlands often is much higher than subsistence of rural communities alone.

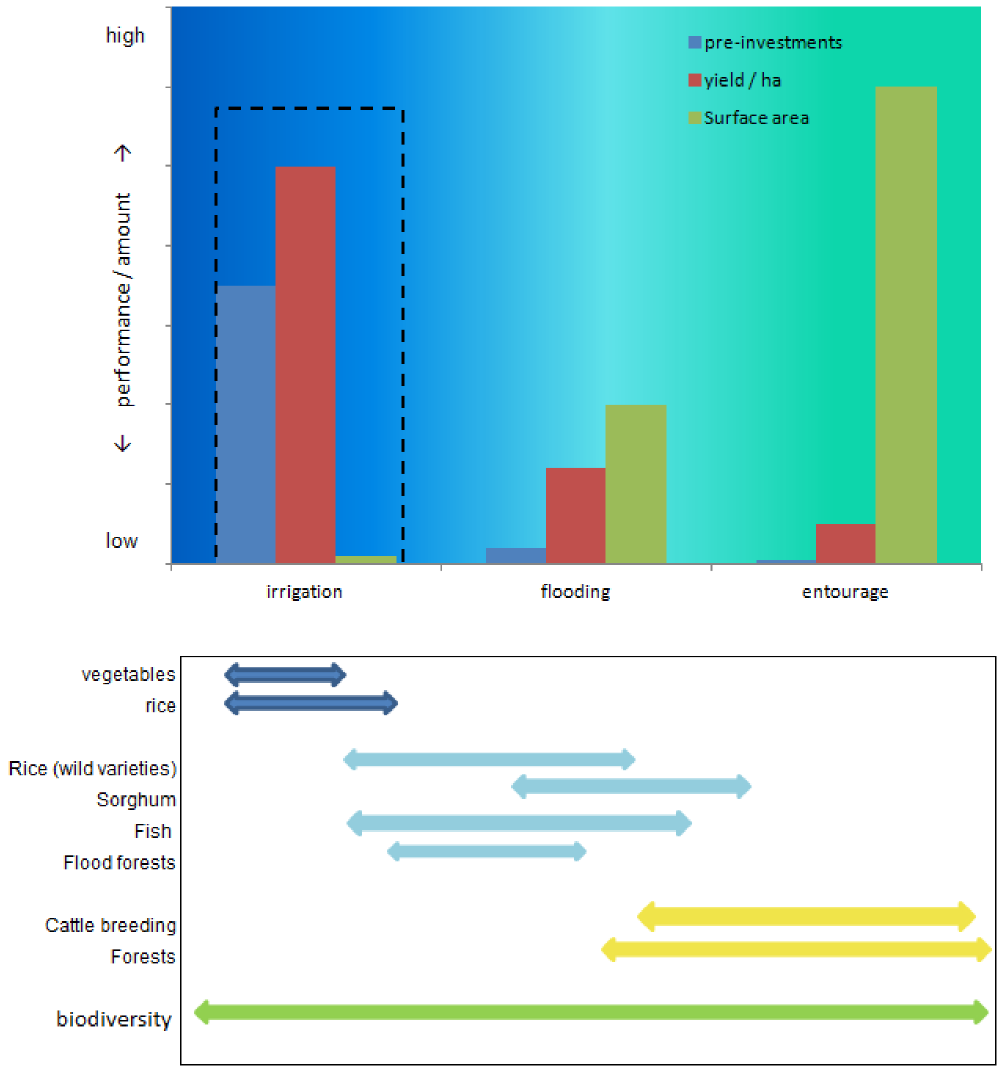


Figure 7.1. Indicative comparison of pre-investments, yields and surface area needed for provisioning services in wetlands in relation to the hydrological regime. Note that these services are only partly interchangeable. The striped block of irrigation illustrates the embankment needed to control water levels.

7.2 What is an efficient approach to assess ecosystem services on basin level?

To assess the ecosystem services in a transparent and verifiable way, in this study we broadly followed the MAES approach, which comprises a step-by-step analysis to assess the ecosystem services per study site. In addition, and very valuable in this context, an economic evaluation of the monetary values of ecosystem services was carried out by Seck (2015). Because of the dependency on water conditions, much effort was put into making water maps that show the variation in time and space. This was done by analyzing satellite images with an automated water extraction method. This method provides an objective overview of wetlands and water cover, irrespective of their conservation status. Although the water extraction index is an accurate method to map areas of open water, a manual correction was needed to incorporate areas that are covered by (semi-)aquatic vegetation. All in all, linking the MAES approach to remote sensing analysis of water availability does not only provide an overview of ecosystem services and monetary values, but also gave insight into the processes that govern these services (chapters 4-6).

For a basin-wide approach the process we followed may be too labour-intensive. However, based on the experiences in the pilots we are able to propose an efficient strategy. First of all, the analyses in this report show that water availability as well as the dynamic nature of the floods, are the overriding factors that govern ecosystem services in the northern part of the Senegal River Basin (<400 mm rainfall). This means, that spatial mapping of permanent or seasonal water cover will catch the majority of provisioning services. When this is combined with mapping the agricultural infrastructure and forests, all provisioning and several regulating functions are incorporated (Table 7.2). This approach facilitates a relatively straightforward and efficient way of assessing the value of wetlands on a basin-wide level. To quantify the socio-economic significance of these wetlands, especially for planning and decision making (see next section) it is necessary to know what a km^2 represents in terms of economic value. A global assessment of 'value units' for a given area of wetland in the arid, semi-arid and humid zones of the basin, will facilitate incorporating wetland values in planning and decision making.

Table 7.2: Mapping of permanent and seasonal water resources, agricultural infrastructures (rice fields, parcels for vegetables) and forests (including flood forests) encompass the core of provisioning services of wetlands in the arid zones of the basin.

Method / type of services	Mapping waterlogged areas (permanent / seasonal)	Mapping cultivated areas (crop type, status)	Mapping Forests (flood forests, other forests)
Provisioning services	V	V	V
Regulating services	V		V
Supporting services	V		V
Cultural services			
Ecosystems & biodiversity	V hotspots		V

As an example for the development of 'value units' fish production in wetlands can be used. From the work of Laë & Leveque (1999) and Zwarts *et al*. (2005) we know that the production of fish is directly linked to the surface area of wetlands (permanent water and/or flooded). As a rule of thumb, 100 km^2 of wetland (lake, flooded area) produces 1000 ton fish per year, and 1000 km^2 produces about 9.000 ton fish/year (the linear relationship is not linear). The same approach can be done for cultivated land (average crop yield per rainfall zone) and forests. Even pastoralism (livestock) can be linked to wetlands, as the surface area of grazing grounds in wetlands during the dry season is an important parameter that defines carrying capacity for livestock in a much wider area. In this approach, it is possible to have an objective overview of the economic potential of wetlands to the local population.

It is important to realise, that an economic valuation alone is not telling the whole story. Some important values of wetlands are difficult to be valued financially, like some of the regulating, supporting and cultural services. These services are however the backbone of the system and in that sense invaluable (e.g. flood dynamics). The maintenance of wetlands and their services supports a significant part of the communities living in the Senegal River Basin, who have no alternative once these services cease to exist.

7.3 The use of wetland values in decision making in the Senegal River Basin

The future of the Senegal River Basin and its inhabitants will be shaped to a large extent by large-scale changes, such as climate change, population growth and the socio-economic development of the OMVS member states. The future water management of the Senegal River's water resources will play a pivotal role in mitigating the huge challenge of climate change in this vulnerable region, and also control and direct the economic growth and direction of growth.

The SDAGE (*Schéma Directeur d'Aménagement et de Gestion des Eaux du fleuve Sénégal, 2011)* of the OMVS provides the framework and guiding document for these developments. As outlined in the Introduction (section 1.2) integrated water resource management (IWRM) is a leading principle for water management as envisaged in the SDAGE. On policy level, this is the strategic link with the safeguarding wetlands, and inclusion of their subsistence and values in decision making and planning in the basin.

The IWRM-process
For the definition of the process of IWRM we use here the definition of the Global Water Partnership (www.gwp.org): '*Integrated Water Resources Management (IWRM) is a process which promotes the coordinated development and management of water, land and related resources in order to maximise economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems*.'

On a basin level, IWRM helps to protect the environment, foster economic growth and sustainable (agricultural) development, promote democratic participation in governance, and improve human health (www.gwp.org). The basis of IWRM is that the different uses of water resources are interdependent. In short, IWRM advocates and stimulates a cross-sectoral integration of water use (stakeholders), based on the principle that water is needed for I) people, II) food, III) nature (ecosystems and biodiversity) and IV) industry and other uses. In particular in Sahelian river basins with highly variable precipitation patterns, IWRM is important with respect to upstream and downstream interests (see e.g. Zwarts *et al*. 2005 for the Upper Niger Basin).

Ecosystem functioning and their benefits to communities are an integral part of the IWRM framework. Therefore, the IWRM approach in the SDAGE is an appropriate entry point to include ecosystems and their values in planning and decision making in the Senegal River Basin.

The role of ecosystem services in the IWRM-process
As has been shown for the study sites, the ecosystem services of wetlands have many aspects, most of these having a direct link with the water management in the basin. Patterns in water availability in the basin – and consequently also land use and ecosystem services – have been significantly altered by changes in the Senegal River, most importantly the construction of the Manantali and Diama dams in the 1980s. Currently roughly 50% of the inflow in the Senegal River is controlled through artificial water discharge at the Manantali; the other half consists of natural inflow from the Bakoye, Falémé and other tributaries. For the near future, IWRM in the Senegal River Basin will focus on optimization of socio-economic development. Important questions are how this can be done sustainably, how to increase food security, and how climate change can be mitigated. Where and how can ecosystem services be included in these issues?

Provisioning services

As has been shown in this pilot study, provisioning services can be mapped and quantified, and fully related to water management, and thus are particularly relevant to include in a IWRM decision making process. For instance, Zwarts *et al*. (2005) showed for the Upper Niger Basin how these services, expressed in economically relevant values, can help to balance upstream and downstream interests. This ES approach facilitates the language needed to incorporate the interest of wetlands in the playing field of other interests. As stated in the former section, it should be realized that not all ecosystem functions can be quantified in terms of yields or economic interest, while these may be the very values that are fundamental to the entire system.

Regulating and supporting services

On basin level these regulating services refer to e.g. climate regulation, water regulation (flood mitigation), water purification, regulation of erosion and pollination. On pilot level (Table 7.2.) also disease and pest control are relevant. All of these services are difficult to map and quantify, with the exception of flooding. However, all these services are crucial in IWRM context to ensure the development of a vital ecosystem. On basin level, the role of wetlands in water regulation and purification is crucial. Existing floodplains, or rehabilitation of floodplains (such as envisaged for the Ndiael), may play a crucial role in preventing the suburban region of Saint Louis to be flooded during extreme floods. In addition, Dakar as well as Nouakchott are largely dependent on wetlands in the Senegal River Basin for their potable water.

Table 7.3. Regulating services

Group	**Class**	**Actual use**	**Constraints and risks**
Disease control	Waterborne diseases (human)	Disease control through supply of fresh water for drinking	• A reported decrease in water quality • Increase in diseases e.g. bilharzia, malaria, dysentery etc in human population
	Waterborne diseases (livestock)	Disease control through supply of fresh water for drinking	• A reported decrease in water quality • Decreasing condition of cattle and seemingly high mortality
Pest control	Invasive species	Pest control through natural hydrological cycle	• Expansion of Typha reedbeds due to changes in hydrology • Expansion of e.g. Water primrose, Azolla sp., Kariba weed, Water hyacinth etc. • Expansion of invasive species (see above) may lead to blockage of water bodies, increased stagnancy, presence of parasites such as bilharzia, and negative impacts on local biodiversity
Ecosystem health	Biodiversity	Species diversity, habitat availability etc through presence of water in arid landscape	• Decrease in water quantity and quantity (see above) • Invasive species (see above) • Increased hunting pressure during dry years???
Flood regulation and protection	Water storage	Wetlands holding water	• Wetland degradation • Drought
Climate regulation	Climate	Proper wetland functioning	• Wetland degradation • Drought

Cultural services

These services are not assessed in this study but essential for the lives of many rural communities. In the IWRM process these values may be addressed properly through stakeholder consultation. There may be also large differences from region to region, partly linked to different communities and traditions.

Biodiversity and ecosystems

Biodiversity and ecosystems is an integral part of the ES approach; the assessment of these wetlands values can be done through mapping of indicators of these ecosystems (water maps, forests, biodiversity, populations of endangered species etc). However, an economic valuation is difficult. Sometimes, the monetary value of the 'willingness to pay' is used as the value unit to account for these services. But these are approaches which only can give an approximation of the value of these services. For the communities in the basin there is a intrinsic value to safeguard the characteristic representatives of the typical ecosystems; also the major importance of the wetlands of the Senegal River Basin for international migratory birds (Zwarts *et al*. 2009, Zwarts et al. 2015) is hard to be valued financially. What can be done however is to map ecological hotspots for biodiversity which are crucial to the functioning of the system. This can be included in the mapping as suggested in the former section.

The situation regarding wetlands – their status, health, area, and benefits to local communities – differs from region to region, depending on rainfall, the extent of degradation and position in the basin. For the basin as a whole the SDAGE is the guiding document; on the level of sub basins one might think of the development of planning instruments on a regional level (SAGE). These may be able to capture the regional values of wetlands and their benefits to the relevant communities.

Constraints, risks and mitigation

The constraints and risks pertaining to ecosystem services relate mostly to the uncertainty in water availability. This uncertainty relates to both annual fluctuations in rainfall as well as long-term precipitation trends. Although the Sahelian study sites are located in identical climatic conditions, local land use and ecosystem services are strongly dependent on the setting relative to the Senegal River. This is well illustrated by the three study sites in northern Senegal and southern Mauritania:

- Lac R'kiz is situated on a dead end of a few inlets that branch off the Senegal River, most importantly the Laouvaja. Low rainfall and high evaporation rates mean that rain-fed agriculture is not feasible, making the system entirely dependent on water inflow through the inlets. During dry years, the lake itself will largely dry out. Possibilities for irrigated agriculture are limited and small-scale vegetable gardening is restricted to a small strip around the Laouvaja. Land use in this area is thus very sensitive to fluctuations in water availability, reduced water quality due to increased stagnancy, and reduced inflow caused e.g. by the spread of *Typha* in the inlets.
- The middle valley is situated in a similar arid environment as Lac R'kiz, but its position along the Senegal River (or its side-arms such as the Gayo or Doué) means that water availability is basically guaranteed, even during dry years. No issues with water quality were reported by the villagers in Thielao. This does not mean that nothing is going on here – in the period after the construction of the Manantali dam the middle valley has seen a major change in land use, i.e. the large-scale conversion from flood-recession agriculture (mainly sorghum) to irrigated rice production. This conversion has caused

considerable social and environmental impacts (see Crousse *et al*. 1991, Horowitz & Salem-Murdock 1993, Jobin 1999, DeGeorges & Reilly 2006, Kitissou *et al*. 2007, Zwarts *et al*. 2009, Dumas *et al*. 2010).

- Lac de Guiers is in many aspects the Senegalese equivalent of Lac R'kiz: an isolated, shallow lake which is connected to the Senegal River by the Taoué, the only source of water feeding the lake. However, the Taoué is an artificial canal that is actively managed, for example by removing *Typha* along its banks. Water availability in the lake is therefore quite stable; the maximum size of the lake has barely changed over the last 15 years. The proximity of the Senegal River has allowed the large-scale development of industrial sugar cane production, as well as some smaller areas where rice and vegetables are cultivated.

It is evident that of the three Sahelian study sites, ecosystem services around Lac R'kiz are the most sensitive to climatic uncertainty. Considerable annual fluctuations in rainfall are characteristic of the Sahel (LeBarbé *et al*. 2002, Zeng 2003, Zwarts *et al*. 2009, Ickowicz *et al*. 2012). In the 20th century some pronounced wet periods occurred, mainly in the first half of the century, as well as long-lasting droughts such as in the 1970s and 1980s. Rainfall seems to be recovering in the last two decades, with 2010 being the wettest year since 1958 (Sanogo *et al*. 2015). This recovery has been attributed to an increase in the intensity of rainfall rather than an increase in rainy days (Giannini *et al*. 2013). The year of 2014 has been dry, however, and the impacts on local land use and ecosystem services were clearly visible during this study.

The constraints and risks as experienced in the study sites might be an important avenue to develop conservation strategies and plans for mitigation of impact of water management. A clear example is the situation of Lac de Guiers. The management of the lake by Office du Lac de Guiers (OLAG) is largely directed towards safeguarding the function as potable water reservoir for the city of Dakar. This may have had consequences for the wetlands values of the lake in the past. Mitigation possibilities in the lake itself are limited, given the requirements for the leading function: potable water supply. However, the adjoining basin of the Ndiael gives ample opportunities for wetland restoration, through rehabilitation of the floods (Bos *et al*. 2015). This is supported by the Office du Lac de Guiers. This is a good example how restoration of wetland values should be considerate on a regional scale rather than on a local scale.

7.4 Recommendations

- The pilot studies have delivered a good insight in the values of wetlands and benefits to local communities, much supported by a separate study on the economic values of these wetland services. We recommend to use the ES-approach to take into account wetland values on a basin level.

- To facilitate the development of an efficient knowledgebase on wetlands and their values in the Senegal River Basin, we recommend mapping of several key parameters as worked out in this report. The combination with an economic valuation of provisioning services and inclusion of the values of other regulating and supporting services, is recommended as well.

- It is to be recommended that the approach which is followed in the Senegal River Basin is tuned to IWRM processes in the Upper Niger River Basin and other Sahelian river systems. There is much to be gained on the exchange of knowledge, data and methods.

- There are multiple opportunities to link the running initiative on the inclusion of ES in the planning and decision making processes in the basin to other initiatives and projects in the region, such as the sustainable development of the Senegalese coastline in combination with flood mitigation of Saint Louis, the introduction of innovative ways of Typha control, and other projects.

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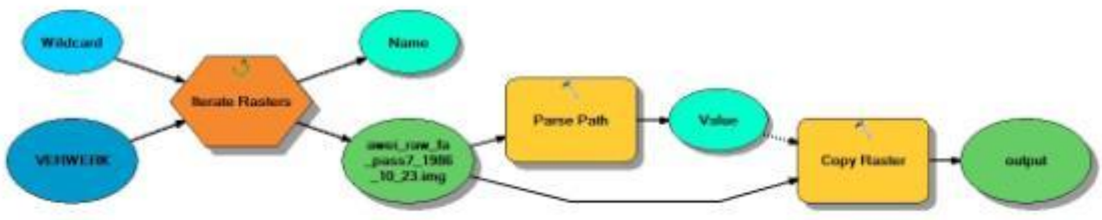
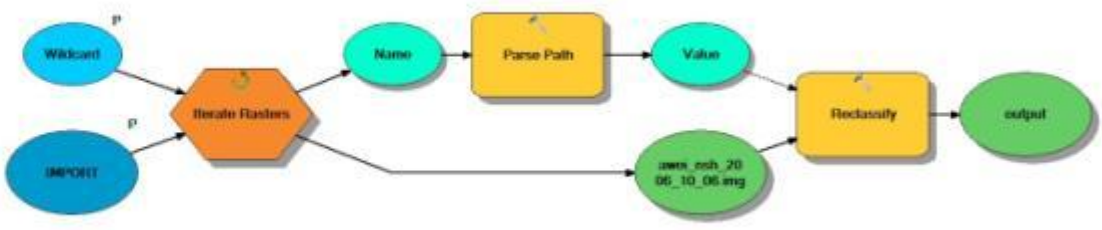
Bijlage 1 GIS analysis of water cover

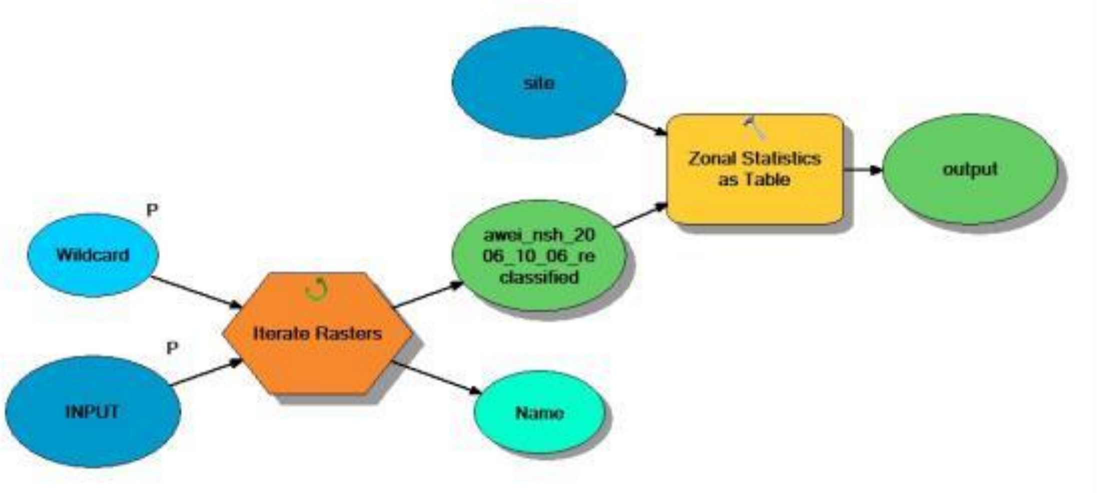
Model step 0: Import original Landstat stack



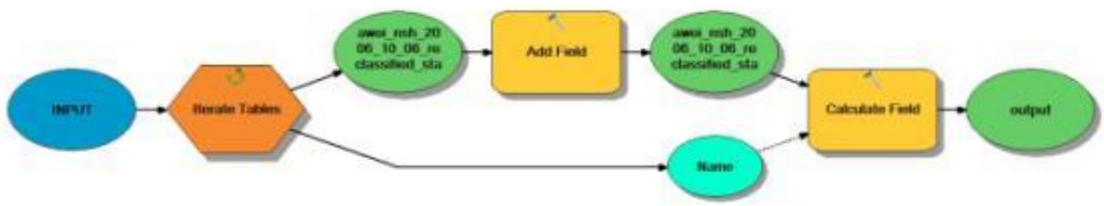
Model step 1: Reclassify and import to temporary database



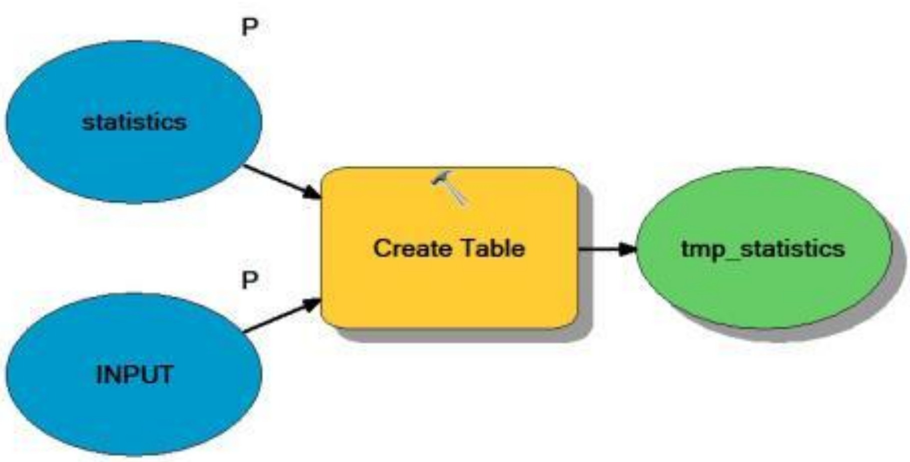
Model step 2: Calculate zonal statistics



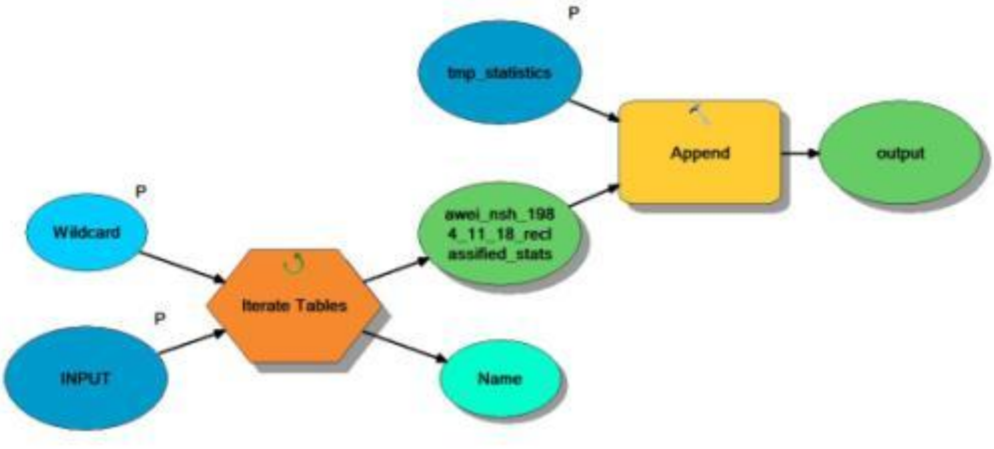
Model step 3: Add field name



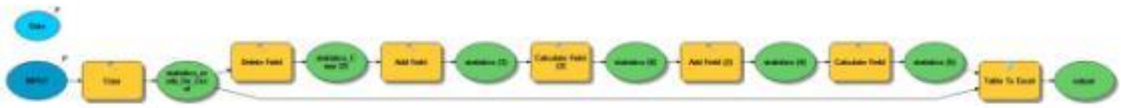
Model step 4: Create template statistisc table



Model step 5: Combine statistics



Model step 6: Export to csv



Bijlage 2 Waterbirds Lac R'kiz

Lac R'kiz is of importance to various species of birds including resident species and large numbers of Palearctic migrants. Waterbirds in the Lac R'kiz area have been counted as part of the African-Eurasian Waterbird Census (AFWC) coordinated by Wetlands International. Data are available from nine counts between 1971 and 2001, which were carried out in one day in the months of November, December or January at various locations around the lake. A summary of these counts is given in Table 1 and 2; a more detailed overview is given in Appendix 2. Normally, around 10–20 species of waterbirds were counted with an exceptional 30 species in January 1999. The total numbers counted in 2000 and 2001 were extremely high, reaching almost 50,000 birds in January 2001. These consisted mostly of Garganey (17,000) and Ruff (nearly 23,000).

In total 46 species of waterbirds have been counted, with the highest numbers (both in species and in counted birds) among ducks (family Anatidae) and sandpipers (family Scolopacidae). By far the most abundant species during the census were Garganey, Ruff and Northern pintail; these three species together comprise 86% of all waterbirds that were counted. These figures show the importance of Lac R'kiz for migratory birds: roughly 88% of all birds that were counted are strictly migratory. These Palearctic migrants comprise all observed sandpiper species, Black-tailed godwit, White and Black stork, Eurasian marsh harrier etc. Only 12% of the observed waterbirds are resident or partly resident, such as Cattle egret, Egyptian goose, Long-tailed cormorant etc.

Table 1. Summary statistics of the AFWC waterbird counts around Lac R'kiz.

Date	Species	Totals
17-jan-72	13	1368
05-nov-74	11	7595
05-nov-75	7	5070
06-dec-75	11	11234
11-jan-87	2	130
19-jan-96	19	1064
15-jan-99	30	3815
13-jan-00	19	29833
15-jan-01	15	49035

During the field trip in March 2015, a few wetland bird species were observed around the lake that have not been observed during the AFWC counts, namely Common moorhen, Collared pratincole and Little ringed plover. In addition to the 'true' waterbirds, several other bird species are attracted by the water in the lake or the insects that are associated with it, such as Barn swallow, Sand martin, Yellow wagtail and Blue-cheeked bee-eater. Some of these species (the plover, swallows/martins and wagtails) are strictly migratory. The semi-desert habitats around Lac R'kiz are home to some resident species that are characteristic of arid Sahelian ecosystems, such as Blue-naped mousebird, Black scrub-robin, Chestnut-bellied starling, Sudan golden sparrow etc. The *Balanites* and *Acacia* trees in the wider region provide shelter and food (insects) to several migratory passerines such as Common whitethroat, Subalpine warbler, Western olivaceous warbler and Common chiffchaff.

Table 2. Overview of the species and bird numbers per family counted during the AFWC waterbird censuses around Lac R'kiz. Source: Wetlands International.

Family (English)	Family	Species	Totals	Mean
Birds of prey	Accipitridae	1	8	1
Cormorants	Phalacrocoracidae	2	124	14
Ducks, swans and geese	Anatidae	11	68948	7661
Gulls and terns	Laridae	1	60	7
Herons	Ardeidae	6	7158	795
Jacanas	Jacanidae	1	5	1
Pelicans	Pelecanidae	1	932	104
Plovers and allies	Charadriidae	2	47	5
Rails	Rallidae	1	25	3
Sandpipers and allies	Scolopacidae	10	29838	3315
Spoonbills and ibises	Threskiornithidae	3	620	69
Stilts and avocets	Recurvirostridae	1	421	47
Storks	Ciconiidae	5	1516	168
Thick-knees	Burhinidae	1	46	5

The table below gives an overview of all waterbirds counted in Lac R'kiz area during the African-Eurasian Waterbird Census in the period 1972 – 2001.

English name	17-1-1972	5-11-1974	5-11-1975	6-12-1975	11-1-1987	19-1-1996	15-1-1999	13-1-2000	15-1-2001	Mean
Marsh Harrier	0	0	0	0	0	1	6	1	0	1
Great Cormorant	0	0	0	15	0	9	45	6	0	8
Long-tailed Cormorant	0	0	0	0	0	0	19	30	0	5
African Pygmy Goose	25	0	0	0	0	0	0	0	0	3
Comb Duck	40	63	50	0	0	0	82	425	0	73
Egyptian Goose	0	0	0	0	0	0	58	12	0	8
Ferruginous Duck	3	0	0	0	0	0	0	0	0	0
Fulvous Whistling Duck	0	0	0	25	0	0	6	0	0	3
Garganey	590	4000	100	2000	0	0	1960	25475	16816	5660
Northern Pintail	240	150	0	8000	0	0	30	27	6160	1623
Northern Shoveler	22	0	0	0	0	0	12	0	0	4
Spur-winged Goose	4	1	220	290	0	1	6	398	172	121
unidentified whistling ducks	0	0	600	0	0	0	0	0	0	67
White-faced Whistling Duck	10	30	0	400	0	13	12	420	0	98
Lesser Black-backed Gull	0	0	0	0	0	0	0	0	60	7
Cattle Egret	0	0	0	0	0	30	1180	1810	1861	542
Great White Egret	0	0	0	0	0	96	28	584	484	132
Grey Heron	0	0	0	0	0	0	0	230	313	60
Little Egret	0	0	0	0	0	0	130	97	236	51

Purple Heron	0	0	0	0	0	0	12	0	0	1
Squacco Heron	0	0	0	0	0	5	9	53	0	7
Great White Pelican	10	150	0	0	110	541	0	0	121	104
Ringed Plover	0	0	0	0	0	10	0	0	0	1
Spur-winged Plover	0	0	0	0	0	15	22	0	0	4
Purple Swamphen	0	0	0	0	0	8	17	0	0	3
African Jacana	0	0	0	0	0	0	5	0	0	1
Black-tailed Godwit	30	0	1000	0	0	1	0	0	16	116
Common Sandpiper	0	0	0	0	0	0	16	0	0	2
Great Snipe	0	0	0	0	0	0	0	145	0	16
Greenshank	0	0	0	0	0	0	1	0	0	0
Little Stint	0	0	0	0	0	140	0	0	0	16
Marsh Sandpiper	0	0	0	0	0	2	1	0	0	0
Redshank	0	0	0	0	0	7	0	0	0	1
Ruff	0	2700	3000	0	0	152	0	0	22612	3163
Spotted Redshank	0	0	0	0	0	0	2	0	0	0
Wood Sandpiper	0	0	0	0	0	11	2	0	0	1
Glossy Ibis	0	30	0	3	0	0	60	190	119	45
Sacred Ibis	0	30	0	1	0	0	0	0	0	3
White Spoonbill	30	0	0	0	20	0	6	0	131	21
Black-winged Stilt	0	0	0	0	0	37	4	220	160	47
Black Stork	14	0	0	0	0	0	0	0	16	3
Marabou Stork	0	0	0	65	0	0	0	0	0	7
White Stork	0	340	100	270	0	0	92	1	0	89
Woolly-necked Stork	0	0	0	0	0	0	1	0	0	0
Yellow-billed Stork	350	101	0	165	0	0	0	1	0	69
Senegal Thick-knee	0	0	0	0	0	33	13	0	0	5
Total species	13	11	7	11	2	19	30	19	15	46
Total numbers	1368	7595	5070	11234	130	1112	3837	30125	49277	12194

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