IMPROVED **D**ROUGHT **E**ARLY **W**ARNING AND **FOR**ECASTING TO STRENGTHEN PREPAREDNESS AND ADAPTATION TO DROUGHTS IN **A**FRICA

DEWFORA

A 7th Framework Programme Collaborative Research Project

Implementation of improved methodologies in comparative case studies

Final report for each case study: Niger river basin

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Lead Author	Fournet Samuel
Contributors	Aich Valentin Dutra Emmanuel Gaspirc Romana Hoffmann Peter Koné Bakary Liersch Stefan Pappenberg Florian van Weerts Frank Zwarts Léo
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SUMMARY

The Niger River basin experiences a high seasonal and interrannual climate variability with severe dry episods affecting the regional food security and socio-economic development as well as the conservation of wetlands and semi-arid ecosystems. It results in an increasing competition and conflicts for water and natural resources between vulnerable local stakeholders (rainfed and semi-controlled irrigation farming, nomadic pastoralism, traditional fisheries) and steers national investments with the construction of dams and diversion channels for the development of hydropower energy and fully governed irrigated agriculture. In this context, the use of tailored hydrological model can improve drought preparedness contingency planning and strategic decision-making at river basin and community scales.

The research problematic of the Niger case study in DEWFORA is to formalize the chains between climate variability, hydrological system, food security and biodiversity maintenance in the Inner Niger Delta in order to address drought vulnerability assessment to upstream water resources and river basin management under climate change and variability and to strengthen adaptation strategies. In a first part, the uncertainties to reproduce the climate distribution and trends will be outlined for three distinct objects of study: past climate, seasonal weather forecast and climate change projection. The aim is to assess the current state of art by comparing the spatio-temporal variability of the different climate data sets for temperature and rainfall and to sound the performance in reproducing monthly, seasonal, annual or decadal climate variability for the case study.

The second part of the report outlines the hydrological characteristics of the basin and highlights the current structure with past to emerging conflicts of the different water uses by introducing the societal status, the right of use and the spatial dynamics of the activities ruling the Niger river Basin and the Inner Niger Delta. It also summarizes in a brief literature review the studies investigating the climate impacts for the Niger basin. Then, this chapter aims at presenting two modeling applications. The Soil and Water Integrated Model (SWIM) projects long term hydrological drought pattern using ISI-MIP Earth System Models in the Upper Niger Basin and the Inner Niger Delta under upstream river basin management scenarii. Calibrated with Watch Forcing Data, SWIM incorporates different scenarii of main operationnal water managements of the river basin (reservoirs and water uptake from irrigation schemes) as well as an inundation module accounting for flood propagation processes in the Inner Niger Delta. Based on water level time series, the skill of the statistical model OPIDIN (Outil de prédiction des Inondations du Delta Intérieur du Niger) is assessed for mid term responses and improvements in the dissemination of the forecast information from the early warning system platform are expounded.

The last and conclusive chapter explores regional drought vulnerability and adaptive capacities introducing the Integrated Water Ressources Management frames in the river basin and in the focus case study focus delivering further details on water-use, stakeholder and stakeholder platform as well as the current forecast, early warning system and preparedness plan in place at different levels. It also presents the advancement and the constraints in the development of drought vulnerability indicators for the Inner Niger Delta using SWIM outputs. The last part discusses substantial solutions to strengthen drought preparedness first, with concrete action plans from the Inner Niger Delta to the community scale and second to enhance integrated drought adaptations at the scale of the Niger River Basin.

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1. INTRODUCTION

The DEWFORA project focuses on the test and implementation of existing and developed methodologies on drought monitoring and forecasting. Specific river basin are used to provide in depth analysis of drought monitoring, forecasting and early warning in Africa at different spatial scales. The case studies play an integral role in the project by providing direct interaction with end-users, highlighting the needs for improvement of the existing systems, and challenging the application of the methods developed in the project in real operational settings. Each of the basin case studies has a specific contribution to the project although sharing common objectives to allow comparison across scales and climatic conditions. Among the four case studies, the Niger Basin (Western Africa) focuses on assessing the vulnerability from mid-term drought forecasting to long term climate change projections under upstream water management scenario and on developing adaptation strategies to strengthen preparedness to droughts and to improve food security and human welfare.

1.1 CASE STUDY DESCRIPTION AND FOCUS,

Stretching between the Sahara desert and the Atlantic coast, the Niger is the third African river according to the length (4,200 km) after the Nile and the Congo. The entire basin covers 2,170,500 km² (7.5% of the continent) across six agro-climatic zones and ten countries while the *active* basin covers 1,272,000 km_2 spread over nine countries: Benin, Burkina Faso, Cameroon, Chad, Ivory Coast, Guinea, Mali, Niger and Nigeria, which are all members of the Niger Basin Authority (NBA). Starting its journey in the Fouta Djallon Massif and the Guinean Dorsale that separates the Middle Guinea and the Guinean forest from Sierra Leone and from Liberia, the river receives consistently high amounts of rainfall which contributes to flow northeast towards Sahelian and sub-desertic regions traversing a vast spreading flood plain in Mali known as the Inner Niger Delta (IND).The course across the IND dissipates an appreciable portion of its potential hydraulics through infiltration and evaporatranspiration. Further on, when it reaches the fringes of the Sahara desert, the Niger river turns back by forming a great bend and flowing south and east as the middle Niger river section, then as the lower Niger, to the maritime Niger Delta (20 000 km²) at the Gulf of Guinea, which is reached after being joined by its largest tributary, the Benue River (Andersen et al., 2005).

The DEWFORA project aims to focus on the Inner Niger Delta region which is highly dependent from the hydrological contributions of the upstream catchment. With the combined pressure of climate change and of the current sectorial approaches of the water uses, water conflicts emerge and compromise the perenniality of food security and natural conservation of the Inner Niger Delta (Zwarts et al., 2005).

The drought early warning and forecasting systems in use are generally designed for the needs of national stakeholder to higher organizations and do not produce adapted information that fit to the meso and local initiatives to support drought mitigation strategies on the ground (Hansen et al., 2011, Tall, 2010). The tools have to be optimized to reflect the problematic and the needs of a multiple source of actors. The challenge is then to define an integrated vision across the different scales of intervention and prerogatives to mitigate the vulnerability to drought risks among the water uses.

1.2 OBJECTIVES AND OUTLINE OF THE REPORT

The research problematic of the Niger case study is to formalize the chains between climate variability, hydrological system, food security and biodiversity maintenance in the Inner Niger Delta in order to address drought vulnerability assessment to upstream water resources and river basin management under climate change and variability and to strengthen adaptation strategies.

For this propose, the research framework adopted a downscaling process approach to investigate the drought hazard at different scales which can be also linked to three different approaches of drought (Figure 1): meteorological drought from global to regional scale, hydrological drought from regional to basin scale and socio-economic drought (including agricultural) from basin to local scales. The three major sections are identified to integrate the local scale to the context of regional change resulting from regional climate forcing and upstream river basin planning.

To pass from global to regional scale, the uncertainties to reproduce the climate distribution and trends will be outlined for three distinct objects of study: past climate, seasonal weather forecast and climate change projection. The aim is to assess the current state of art by comparing the spatio-temporal variability of the different climate data sets for temperature and rainfall and to sound the performance in reproducing monthly, seasonal, annual or decadal climate variability for the case study.

To pass from regional to basin scale, the report first outlines the hydrological characteristics of the basin, second, highlights the current structure with past to emerging conflicts of the different water uses by introducing the societal status, the right of use and the spatial dynamics of the activities ruling the Niger river Basin and the Inner Niger Delta. It also summarizes in a brief literature review the studies investigating the climate impacts for the Niger basin. Then, this chapter aims at presenting two modeling applications. The Soil and Water Integrated Model (SWIM) projects long term hydrological drought pattern using ISI-MIP Earth System Models in the Upper Niger Basin and the Inner Niger Delta under upstream river basin management scenarii.. Calibrated with Watch Forcing Data, SWIM incorporates different scenarii of main operationnal water managements of the river basin (reservoirs and water uptake from irrigation schemes) as well as an inundation module accounting for flood propagation processes in the Inner Niger Delta. Based on water level time series, the skill of the statistical model OPIDIN (Outil de prédiction des Inondations du Delta Intérieur du Niger) is assessed for mid term responses and improvements in the dissemination of the forecast information from the early warning system platform are expounded.

From basin to local scale, the “regional drought vulnerability and adaptive capacities” section first introduces the Integrated Water Ressources Management frames in the river basin and in the case study focus delivering further details on water-use, stakeholder and stakeholder platform as well as the current forecast, early warning system and preparedness plan in place at different levels. The second part covers the advancement and the constraints in the development of drought vulnerability indicators for the Inner Niger Delta using SWIM outputs. The last part gives substantial solutions to strengthen drought preparedness first, with concrete action plans from the Inner Niger Delta to the community scale and second to enhance integrated drought adaptations at the scale of the Niger River Basin.

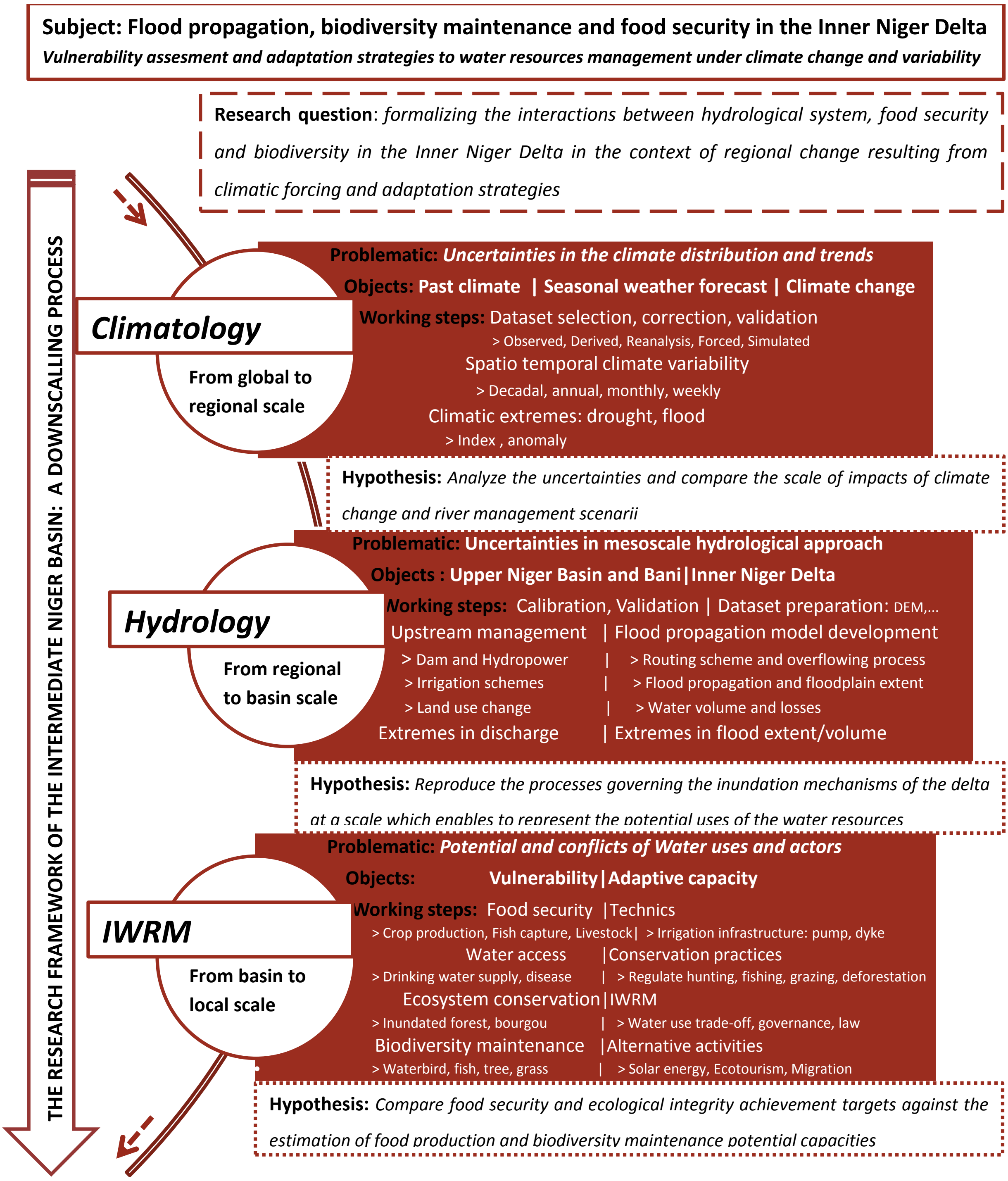


Figure 1: Scheme of the general research framework for the Niger case study

2. CLIMATOLOGY: SKILLS, TRENDS AND UNCERTAINTIES IN SIMULATED METEOROLOGICAL DROUGHT PATTERNS

The West African climate is dominated by a monsoon system, a large-scale oscillation associated with the seasonal reversal of land-sea temperature contrasts. The wet season mainly occurs between June and September, when moist and disturbed winds blow inland from the tropical oceans, bringing most of the annual precipitation. Although the monsoon returns with remarkable regularity each summer, the seasonal amount of rainfall shows a large interannual variability (Hagos et al. 2007). This climatological feature is of major economic and social importance to the population of the region whose economy heavily relies on agriculture. In the Niger basin, agriculture and food production as a whole are extremely localized in nature and national scale food production is almost entirely based on family/village units of production. Understanding its dynamics, variability at various time scales, and ultimately improving skill in predicting its onset and evolution is the key to contribute toward food security and the stability of the region. This chapter aims to present, in separate sections, an updated assessment of the particular skills, trends and uncertainties from climate monitoring, meteorological forecast and climate change products for the Niger case study.

2.1 PAST CLIMATE

Monitored measurements from climatological stations are generally sparse in the Niger River Basin and very inhomogeneously distributed over the Niger catchment especially in the Sahel fringe. In this regard, a reanalysis climate data set produced within EU FP6 WATCH project (Weedon et al. 2011) was used in this study to apply the hydrological model SWIM. Thus, the first sub-section describes the main characteristics of Watch Forcing Data in the Niger River Basin. Secondly, 16 other global gridded datasets of precipitation are then presented and used in order to proceed to an intercomparison analysis of annual to daily precipitation trends and to ultimately validate the use of WATCH Forcing Data for hydrological modelling application.

2.1.1 WATCH Forcing data

WATCH Forcing Data (**WFD**) is a global sub-daily meteorological forcing dataset provided for use with landsurface- and hydrological-models. The data are derived from the **ERA-40** or **ERA-Interim** reanalysis product (**WFD_ERA40 or WFD_ERAI**) via sequential interpolation to half-degree resolution, elevation correction and monthly-scale adjustments based on **CRU** for corrected-temperature, diurnal temperature range and cloud-cover, based on **GPCC or CRU** (**WFD_ERA40_GPCC or WFD_ERA40_CRU)** for precipitation monthly observations also combined with new corrections for varying atmospheric aerosol-loading and separate precipitation gauge corrections for rainfall and snowfall. ERA-40 is the previous generation of global atmospheric reanalysis produced by ECMWF covering the period from mid-1957 to 2001. A new version of WATCH product, derived from ERA-Interim and covering the period 1979 to 2009, was also released. WATCH Forcing data contains all variables required for SWIM on a daily basis on a 0.5°x0.5° grid and the ERA-40 version with the precipitation bias-correction based on GPCC (WFD_ERA40_GPCC) was then used for calibration processes.

A summary of the inter-annual variability (1960-2001) of monthly mean precipitation is presented in the following figure at different locations in the Niger River Basin. The plots show WFD_ERA40_GPCC´s precipitation interpolated at selected sub-basins delineated for the setup of the model SWIM. The rainfall cycle in the basin is strongly governed by the inter-annual variability of the West African monsoon which is determined by a pronounced south-north decreasing gradient for the rainfall season starting in April-June and ending in September-October with a peak in August.

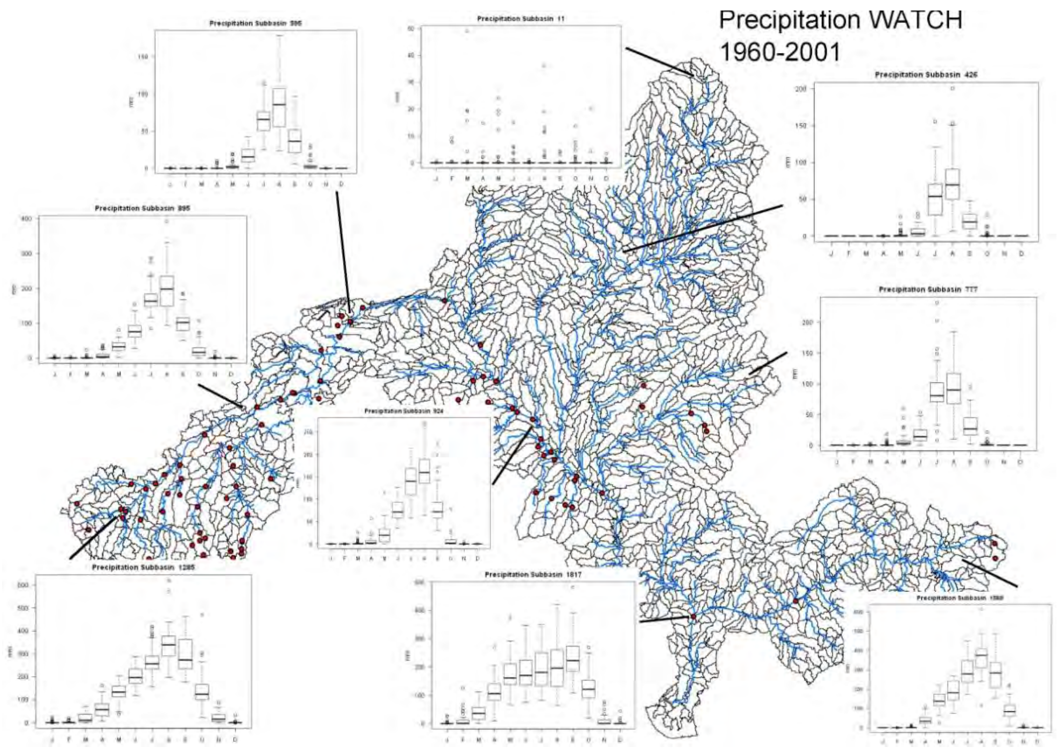


Figure 2: Inter-annual variability (1960-2001) of monthly mean precipitation at different locations in the Niger basin, WATCH_ERA40_GPCC forcing dataset from Aich, PIK

In the Upper Niger basin (Figure 4), the focus area of DEWFORA project, annual climate trends in WFD_ERA40_GPCC (Figure 3) show increasing temperatures (0.2°C per decade) and decreasing rainfall (34 mm per decade, although with long-term cyclic behavior) for the time period 1960-2001.

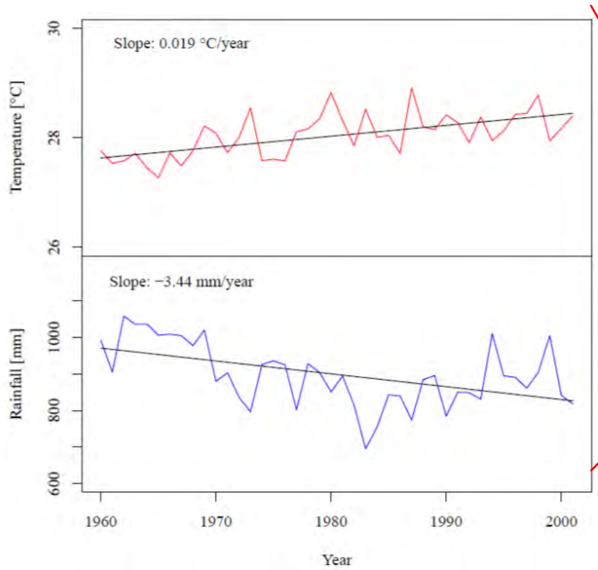


Figure 3: Mean daily annual temperature and annual rainfall trends in the Upper Niger Basin with WFD_ERA40_GPCC, averaged over the Upper Niger region in Liersch et al. 2012

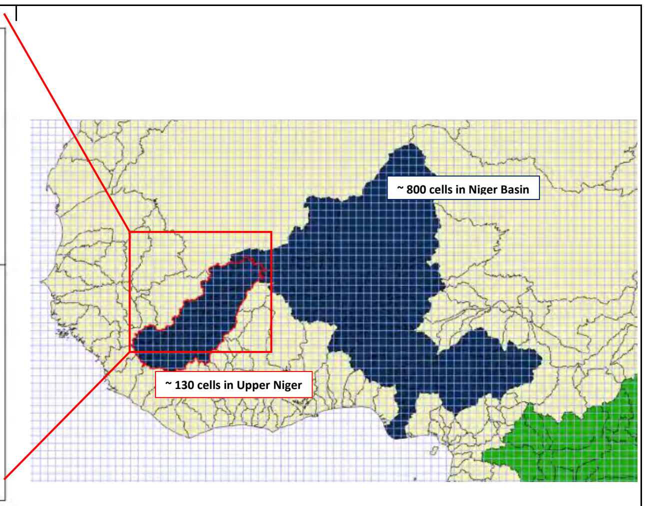


Figure 4: Number of WFD´s cells (0.5 degree resolution) covering the setup of the Upper Niger region and the full Niger basin (Liersch et al. 2012)

2.1.2 Intercomparison analysis of precipitation gridded datasets

This section presents 16 other global gridded datasets of precipitation based on observation, satellite, reanalysis or hybrid monitoring methods in order to proceed to an intercomparison analysis of annual to daily precipitation trends. The first part synthesizes the characteristics of the different precipitation datasets used in this study.

(a) Datasets description

ERA-40 and ERA-Interim are reanalysis datasets from the European Centre for Medium-Range Weather Forecasts (ECMWF). Those two datasets were already the objects of detailed description in previous deliverable in the core of DEWFORA project (Cf. D4.1; D6.1-T6.4; D6.3).

The **NCEP/NCAR Reanalysis 1** (NCEP_REA1 and NCEP_READER) project is using a state-of-the-art analysis/forecast system to perform data assimilation using past data from 1948 to the present. **NCEP-DOE Reanalysis 2** (NCEP_REA2) is an improved version of the NCEP Reanalysis I (NCEP_REA1) model that fixed errors and updated parameterizations of physical processes. The NCEP-DOE Reanalysis 2 project is using a state-of-the-art analysis/forecast system to perform data assimilation using past data from 1979 through the previous year. Finally, the **NCEP/NCAR Reanalysis 1 Derived** (NCEP_READER) was developed by the NOAA/OAR/ESRL PSD with some slight modification in the baseline methodology of the NCEP/NCAR Reanalysis 1.

Reference: Kalnay et al.,The NCEP/NCAR 40-year reanalysis project, Bull. Amer. Meteor. Soc., 77, 437-470, 1996.

Source: NCEP Reanalysis Derived, 1 and 2 data provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, from their Web site at http://www.esrl.noaa.gov/psd/

The **CPC Merged Analysis of Precipitation** ("CMAP") is a technique which produces pentad and monthly analyses of global precipitation in which observations from raingauges are merged with precipitation estimates from several satellite-based algorithms (infrared and microwave). The analyses are on a 2.5° x 2.5° latitude/longitude grid and extend back to 1979. CMAP (CPC Merged Analysis of Precipitation) values are obtained from 5 kinds of satellite estimates (GPI,OPI,SSM/I scattering, SSM/I emission and MSU). The enhanced file (CMAP_enh) also includes blended NCEP/NCAR Reanalysis Precipitation values. The other (CMAP_std) just includes the satellite estimates.

Reference: Xie, P., and P.A. Arkin, 1997: Global precipitation: A 17-year monthly analysis based on gauge observations, satellite estimates, and numerical model outputs. Bull. Amer. Meteor. Soc., 78, 2539 - 2558.

Source: CMAP Precipitation data provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, from their Web site at http://www.esrl.noaa.gov/psd/

NOAA's Precipitation Reconstruction (NOAA_PRECREP) is an analysis of monthly precipitation constructed on a 2.5 lat/lon grid over the global for the period from 1948 to the present. The land portion of this global analysis is defined by optimum interpolation of gauge observations at over 17,000 stations collected in the NOAA/NCDC GHCN Version 2 and the NOAA/CPC CAMS data sets. The oceanic precipitation analysis (PREC/O), meanwhile, is produced by EOF reconstruction of historical gauge observations over islands and land areas. The EOF modes are derived from EOF analysis of the satellite estimates for later years (OPI, 1979-1998) with complete spatial coverage. The current version 1.0 is based on the first 8 EOF global modes for each 4 seasons and the first 4 EOF modes of the residual components of the 8 EOF global modes over Atlantic Ocean areas. The climatology is based on time period of 1951-1990 over land and 1979-1998 over oceans.

Reference: Chen, M., P. Xie, J. E. Janowiak, and P. A. Arkin, 2002: Global Land Precipitation: A 50-yr Monthly Analysis Based on Gauge Observations, J. of Hydrometeorology, 3, 249-266

Source: PREC Precipitation data provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, from their Web site at http://www.esrl.noaa.gov/psd/

The **daily TRMM** and others satellite precipitation products 3B42 v6 and v7 derived (TRMMv6 and TRMMv7) are daily precipitation rate estimate from the Tropical Rainfall Measuring Mission (TRMM), a joint U.S.-Japan satellite mission monitoring tropical and subtropical precipitation and estimating its associated latent heating. The purpose of Algorithm 3B42 is to produce Tropical Rainfall Measuring Mission (TRMM) merged high quality (HQ)/infrared (IR) precipitation and root-mean-square (RMS) precipitation-error estimates. These gridded estimates are on a 3-hour temporal resolution and a 0.25-degree by 0.25-degree spatial resolution in a global belt extending from 50 degrees South to 50 degrees North latitude. The 3B42 estimates are produced in four stages; (1) the microwave precipitation estimates are calibrated and combined, (2) infrared precipitation estimates are created using the calibrated microwave precipitation, (3) the microwave and IR estimates are combined, and (4) rescaling to monthly data is applied. Each precipitation field is best interpreted as the precipitation rate effective at the nominal observation time

Source: http://mirador.gsfc.nasa.gov

The Global Precipitation Climatology Project (**GPCP**) constructs a monthly precipitation dataset from 1979-present combining observations and satellite precipitation data into 2.5°x2.5° global grids. The version 2.2 Combined Precipitation Data Set is used in this study

Reference: The GPCP combined precipitation data were developed and computed by the NASA/Goddard Space Flight Center's Laboratory for Atmospheres as a contribution to the GEWEX Global Precipitation Climatology Project: http://precip.gsfc.nasa.gov/

Source: GPCP data provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, from their Web site at http://www.esrl.noaa.gov/psd/ in any documents

The **University of Delaware** (**UDEL**) hold a monthly global gridded high resolution station (land) data for air temperature and precipitation from 1900-2010.

Reference: Center for Climatic Research Department of Geography University of Delaware Newark, DE 19716

Source: UDel_AirT_Precip data provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, from their Web site at http://www.esrl.noaa.gov/psd/

The Climate Research Unit, University of East Anglia (CRU) constructed different versions of historical monthly precipitation data set for global land areas from 1900 to 1998 which were gridded at two different resolutions (2.5° latitude by 3.75° longitude and 5° latitude/longitude). Three versions are used in this present study (CRU-TS3.0/3.1/3.2).

Source: http://www.cru.uea.ac.uk/data/

The **GPCC Full Data Reanalysis Version 6.0** (at 0.5°, 1.0°, 2.5°) is a Monthly Land-Surface Precipitation dataset from Rain-Gauges built on GTS-based and Historic Data from Deutscher Wetterdienst.

Reference: "GPCC's new land surface precipitation climatology based on quality-controlled in situ data and its role in quantifying the global water cycle", U. Schneider, A. Becker, P. Finger, A. Meyer-Christoffer, M. Ziese, B. Rudolf, Global Precipitation Climatology Centre, Deutscher Wetterdienst, Offenbach, Germany, in Theoretical and Applied Climatology, DOI: http://dx.doi.org/10.1007/s00704-013-0860-x

Source: http://gpcc.dwd.de

(b) Intercomparison analysis

Figure 5 shows the mean annual precipitation in mm in the Upper Niger Basin for the 20 precipitation gridded datasets. To facilitate the interpretation, we consider GPCCFD (pink dashed line) as the baseline benchmark. First, a strong common denominator for the mean annual rainfall between the precipitation datasets mainly based on raingauge (UDEL, CRU´s and GPCCFD) is met with WFD products. This correlation is due to the bias-correction methods applied on WFD based on GPCC or CRU. As a second statement, there are important quantitative and dynamic deviations and divergence from reanalysis datasets (NCEP and ERA products) which points out the constraints to capture the dynamics of the West African monsoon. However, the second version of NCEP products slightly corrects the large underestimation of annual precipitation and has a better performance to reproduce the inter-annual variability patterns. Among the 5 NCEP and ERA products, ERA-Interim is the product which better capture the mean annual precipitation over the catchment even if under-estimation is still pronounced for the last decade. Finally, GPCP, CMAP´s and TRMM´s datasets present a better response than reanalysis data. Figure 6 presents the decadal mean of annual and monthly precipitation in the Upper Niger Basin from 1960 to 1999 to study in depth seasonal and interdecadal bias of the different precipitation products.

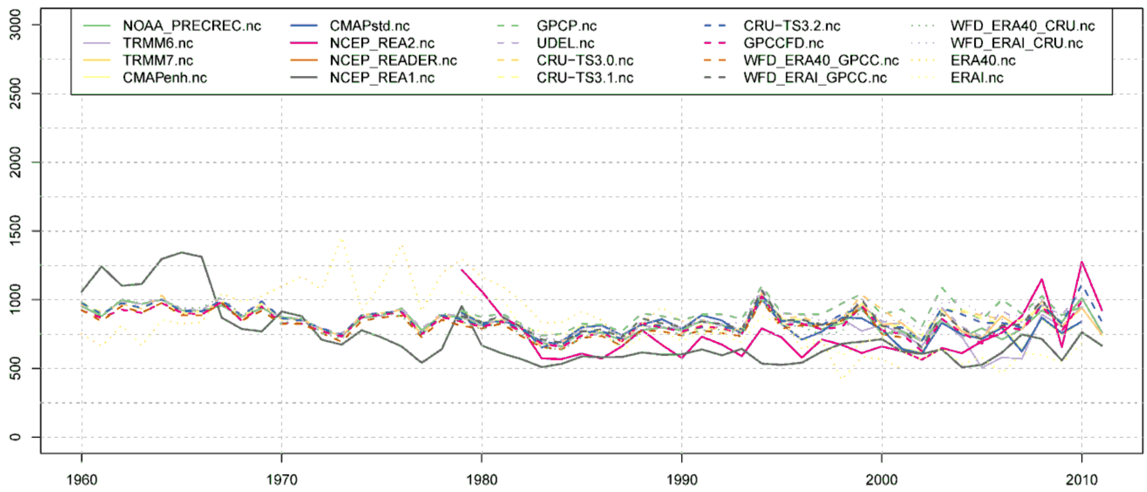


Figure 5: Annual precipitation (mm) in 20 different gridded datasets (observation, satellite, reanalysis and hybrid) in the Upper Niger Basin

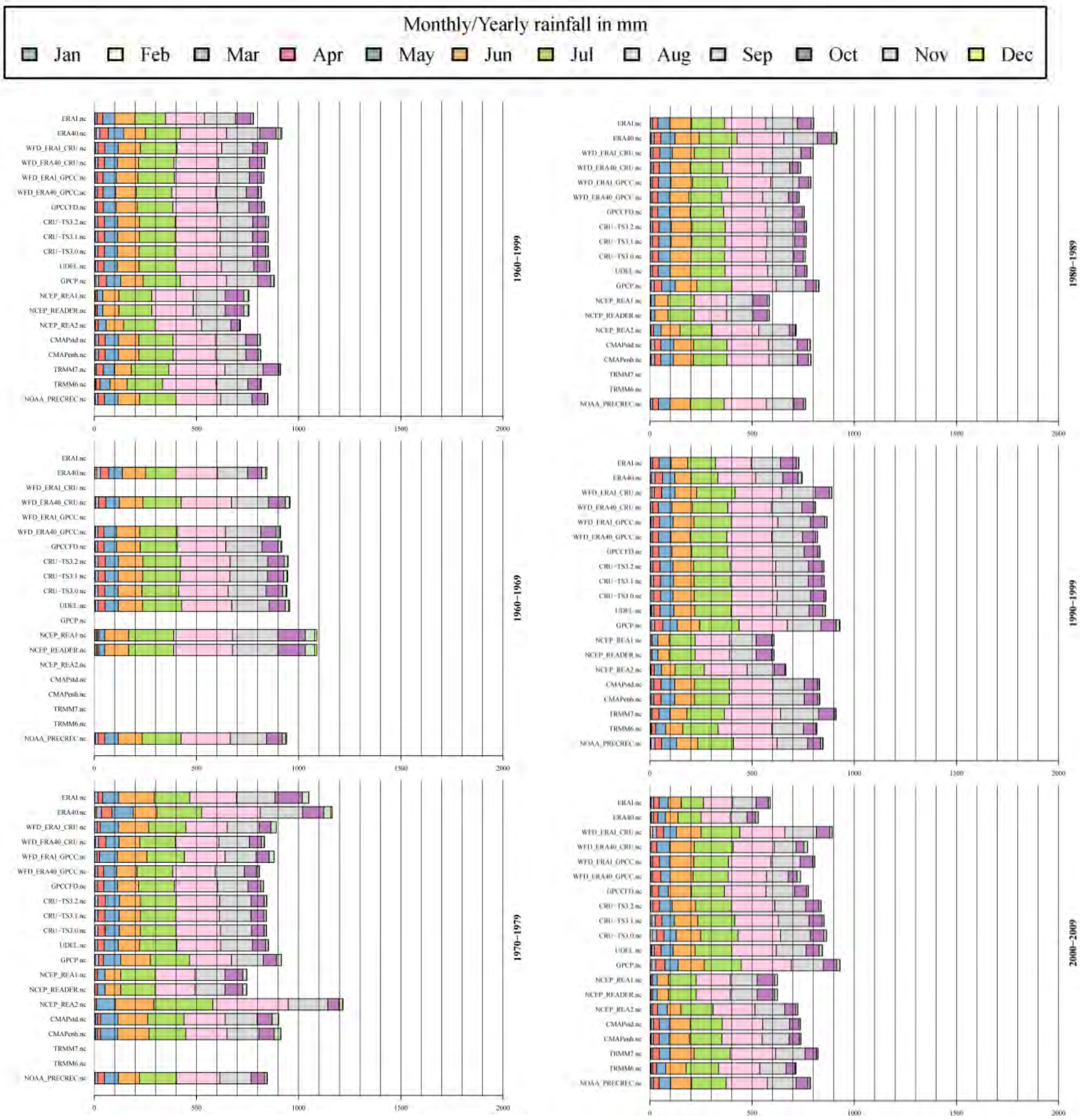


Figure 6: Decadal mean of monthly and annual precipitation (mm) in 20 different gridded datasets (observation, satellite, reanalysis and hybrid) in the Upper Niger Basin
(the mean is built based on the available datasets in the given periods for each datasets)

2.2 SEASONNAL WEATHER FORECAST SKILLS: TEMPERATURE AND PRECIPITATION ANALYSIS

Over the last two decades, the stress has been put on developing seasonal rainfall forecasting models for West Africa, some of them being operationally run in the framework of the Seasonal PREdiction West African annual fora (PRESAO). Taking part to this collaborative institution, ECMWF upgraded their seasonal forecast system in November 2011 (Source: http://www.ecmwf.int/products/changes/system4/). The aim of this section is then to assess the predictive skill of the System 4 for the Niger River case study region.

2.2.1 General skills

Forecasting skill across the globe is routinely assessed at all Numerical Weather Prediction forecasting centers. The Figure 7 presents the anomaly correlation of near-surface air temperature for the entire African continent with 15 ensemble members and two to four months lead time starting in May. It can be seen that the correlations in the Niger regions are low but distinctively positive.

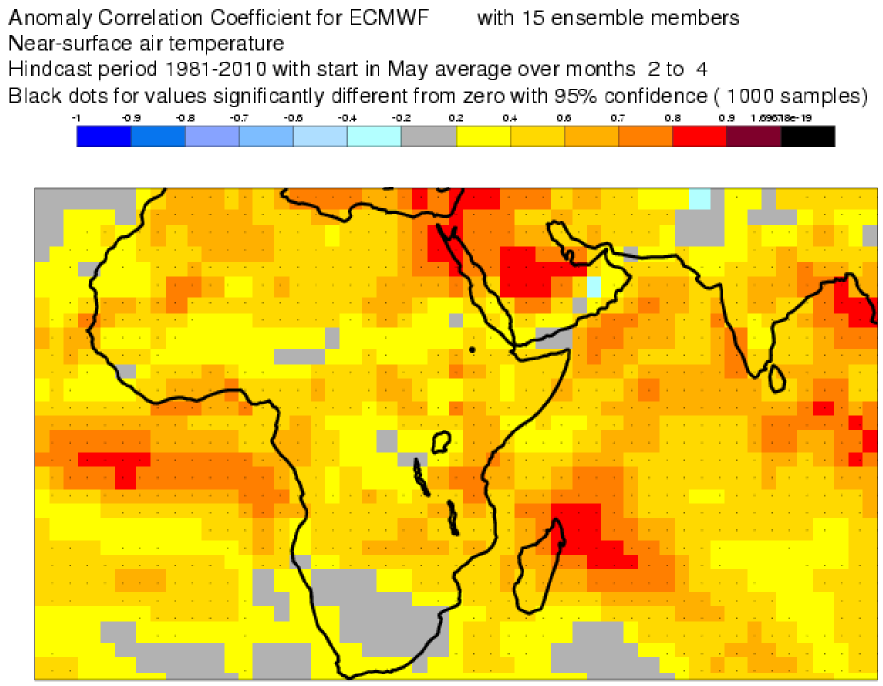


Figure 7: Anomaly Correlation Coefficient over Africa (starting month May with 2 to 4 months lead time).

In the ROC diagram for 2 meter temperature across Africa (Figure 8) is shown for a lead time of 4 months a ROC score superior to 0.5 which indicates skill. The skill score with 0.71 is clearly above 0.5

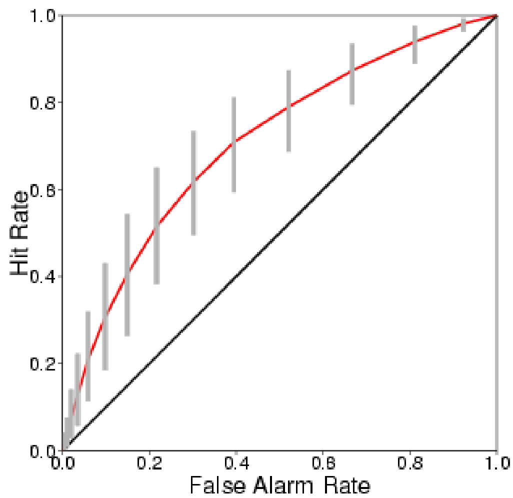


Figure 8: RDC Diagram for ECMWF with 15 ensemble members: Near-surface air temperature anomalies below the lower tercile; Accumulated over Africa (land points only); Hindcast period 1981-2010 with start in May average over months 5 to 7; Skill scores and 95 % confidence intervals (1000 samples); ROC score: 0.710 (0640, 0.760)

An extensive analysis of the performance of various observational and re-analysis products was performed in WP4-D4.3. In Figure 9, the GPCP mean annual cycle of precipitation in the different basins was compared with ERAI, CAMSOPI (see detailed in WP4-D4.3) and S4. In the Niger the rainy season (Jun-Sep) is captured by all datasets. S4 forecasts overestimate precipitation in the Niger basins in the first forecast month with a reduction of the peak rainfall with lead time, showing the impact of model drift.

The mean annual cycle reflects the general behavior and systematic biases of the datasets, but for drought applications the timing of the rainy seasons and its inter-annual variability (Figure 10) are the key factors. Systematic biases are not reflected in the SPI (since it is a normalized measure), but errors in the timing, amplitude and variability will degrade the ability of the dataset to monitor (ERAI, CAMSOPI) and forecast (S4) meteorological droughts.

The inter-annual variability is evaluated as the monthly standard deviation (i.e. variability of a certain month in different years) (Figure 10). The annual cycle of monthly inter-annual variability has a similar behavior to the mean annual cycle of precipitation in all basins. In the Niger, the ERAI overestimation of precipitation is also reflected in higher inter-annual variability. However, in the Niger S4 do not represent the sharp peak variability from June to September, and in the BN July-August have less variability than May or September. The underlying reasons for this behavior are unknown, but can be related with a lack of regional-scale interactions (e.g. with orography, soil moisture) that amplify/damp large scale anomalies.

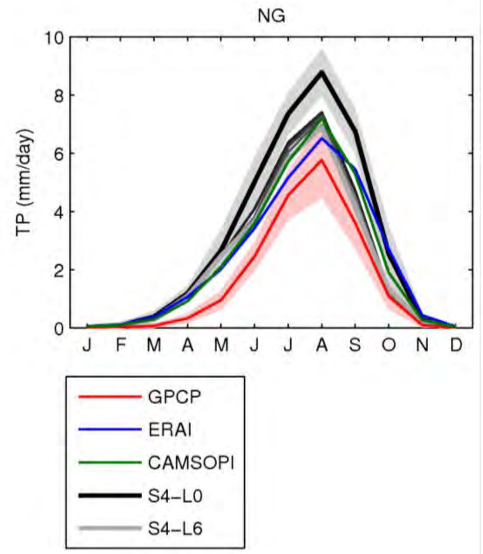


Figure 9: Mean annual cycle of precipitation over the selected basins. The shaded area shows the range (+/- 1 standard deviation) of observed (GPCP-red) and modelled (S4-gray) precipitation over the regions for the hindcast period 1981-2010, comparing with ERAI (blue) and CAMSOPI (green). The time series for the seasonal forecast uses the first month of forecast (lead time 0) and the 15 forecast ensemble members (gray area and thick black), the last month of forecast (lead time 6) in thick gray, and the remaining lead times in thin gray.

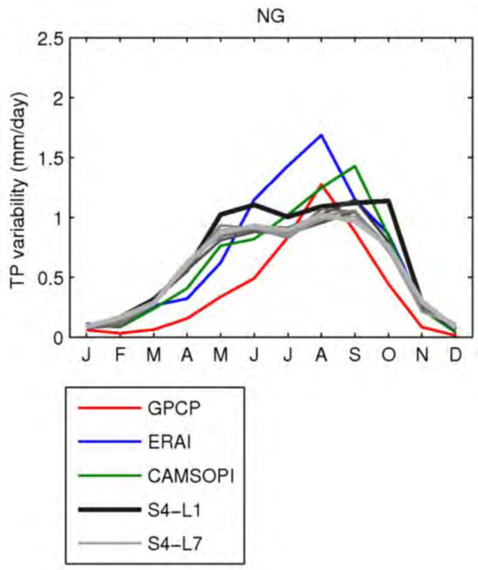


Figure 10: Inter-annual standard deviation of monthly precipitation over the selected basins. Observed (GPCP-red) compared with ERAI (blue), CAMSOPI (green) and S4 for the first month lead time (thick black), 7 months lead time (thick gray) and the remaining lead times (thin gray lines). The S4 standard deviation is takes for each month and lead time considering all the ensemble members (15) and not the ensemble mean.

2.2.2 Skill in predicting droughts

The previous analysis focuses on NWP forecasts of precipitation and temperature. The analysis is set in a meteorological typical framework. Predicting droughts represents a non-linear transformation of these variables and hence skill and performance can change. A detailed analysis of seasonal skill for drought predictions was presented in WP4-D4.3. It could be demonstrated that seasonal forecasting in the Upper Niger show a higher reliability and skill in comparison with other areas in Africa. The skill and reliability depend strongly on the accumulation period and more skill is observed at larger accumulation periods.

The comparison of the SPI-12 calculated from, ERAI, CAMSOPI and GPCP for the different basins is presented in Figure 11. In the Niger the temporal correlation of both ERAI and CAMSOPI compared with GPCP decays with increasing SPI time-scale. These results show inconsistencies of the inter-annual variability between GPCP and the two datasets that penalize the SPI on long accumulation time-scales. The inconsistency is obvious as the accumulation time increases (>6 months), but for the shorter accumulation times, the temporal correlation is seemingly higher. This can however be an artefact of the SPI, which normalises the values and gives equal weight to anomalies in the dry season, which are of little importance.

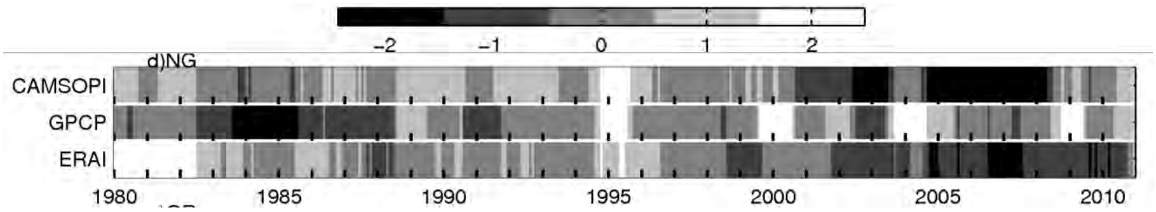


Figure 11: Evolution of the 12-month SPI in the different basins given by CAMSOPI, GPCP and ERAI. The horizontal ticks represent January of each year.

We start by analysing the skill of S4 precipitation forecasts in terms of the anomaly correlation coefficient (ACC) for the ensemble mean for each basin. The 3-month ACC for each forecast month as a function of lead time is represented in Figure 12. In the Niger basins, the seasonal forecasts have skill up to 3 months lead time for the rainy seasons.

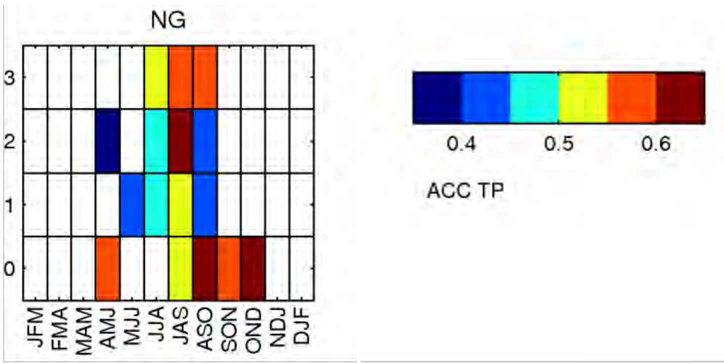


Figure 12: Anomaly correlation coefficient S4 3-months total precipitation as a function of verification season (horizontal axis) and lead time (vertical axis) for the different basins. Only ACC significant at p<0.05 are displayed. For example, the values valid at JJA with lead time 0 (3) corresponds to the forecasts starting in June (March). The forecasts were verified against GPCP for the period 1981 to 2010.

For the SPI seasonal forecasts, we start by assessing the potential skill, i.e. considering that we have access to a perfect monitoring, in this case GPCP (also used as verification). The

ACC and the continuous rank probability skill score (CRPSS) of the SPI-3,6, and 12 are represented in Figure 13 as a function of lead time for the entire time series (30 years handcarts). The continuous rank probability score (CRPS) is a development of the Ranked Probability Score (RPS). It can be interpreted as the integral of the Brier Score over all possible threshold values of the parameter under consideration. In deterministic forecasts, the CRPS is reduced to the mean absolute error. Since the CRPS is not a normalized measure, we evaluate the CRPS skill score (CRPSS). In the skill score calculation the reference forecast (or climatology, CLM) is taken from the verification dataset as sample of different years, to produce a climatological forecast with the same ensemble size as S4, and is merged with the monitoring product, in the same ways and the S4 SPI forecasts. The sampling is not random. It searches in the 30 years of record for 15 (size of the ensemble during the hindcast period) years with similar precipitation amounts during the monitoring.

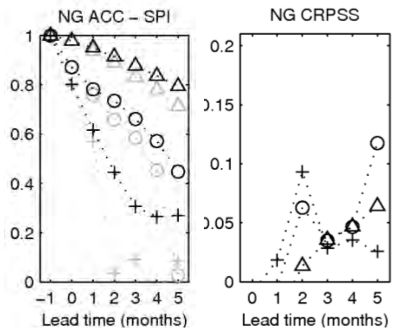


Figure 13: Anomaly correlation coefficient (left panels) and CRPSS (right panels) of S4 (black) and climate (grey) SPI forecasts as a function of lead time for different accumulation times (symbols). GPCP is used for the monitoring and GPCP as verification (ACC == 1 for -1 lead time).

The ACC of the SPI decays in time at a faster rate for lower accumulation periods, where the monitoring importance is reduced or inexistent (Figure 13 upper panel). S4 outperforms the climatological forecasts (CLM) in the Niger where the original seasonal forecasts of precipitation have skill (Figure 13 lower).

Figure 14 represents the FAR versus HT of the 5 month lead time SPI-6 (first 6 months of forecasts – no monitoring used) and SPI-12 (merged 6 months of monitoring with the first 6 months of forecasts) for the different basins of S4 and CLM. The event is defined when the SPI is below -0.8, representing moderate to severe droughts. For the SPI-6 the ROC of CLM is close to 0.5 (no information), while with S4 the ROC is higher close to 0.7 in the Niger. For the SPI-12 the ROC of CLM is always above 0.5, since the climatological forecast inherits 6 months of monitoring. In this case, it is difficult to beat the climate forecast, but S4 outperforms CLM in the Niger basins (as documented before).

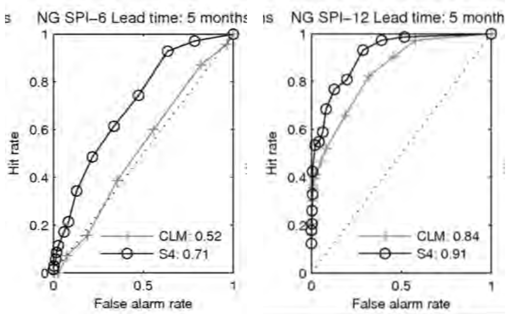


Figure 14: Relative operating characteristic (ROC) diagram representing false alarm rate versus hit rate for the 6 month (left) and 12 month (right) SPI <= -0.8 given by S4 (black) and CLM (grey). ROC values are given in the legend of each panel. Calculations based on 20 thresholds (fraction of ensemble members below -0.8), from 1 (symbols closer to 0.0) to 0 (symbols closer to 1.1).

2.3 LONG TERM GLOBAL AND REGIONAL CLIMATE PROJECTIONS: CMIP5 GCMS, CORDEX, AND ISI-MIP TEMPERATURE AND PRECIPITATION ANALYSIS

2.3.1 CMIP5 GCM

Under the World Climate Research Programme (WCRP) the Working Group on Coupled Modelling (WGCM) established the Coupled Model Intercomparison Project (**CMIP**) as a standard experimental protocol for studying the output of coupled atmosphere-ocean general circulation models (AOGCMs). The CMIP phase 5 outputs are also available under the Inter-Sectoral Impact Model Intercomparison (ISI-MIP) platform (http://www.pik-potsdam.de/research/climate-impacts-and-vulnerabilities/ projects/Externally_RD2/isi-mip) from the Potsdam Institute for Climate Impact Research.

Precipitation and temperature are the key drivers for the hydrological regime of rivers, and climate change has its main impact by means of trends in these two variables. In Figure 15, we show the mean linear trends for these two parameters from 2006 until 2100 projected by 19 CMIP5 models for the whole African continent. Shown are the results for RCP 8.5 in order to illustrate the most pronounced trends under extreme scenario conditions.

All models agree in a distinct temperature rise over the whole African continent while in the tropics much of the additional energy input is converted to latent heat. The highest increase with 6°C to 7°C, partly even up to 8°C is projected over the already driest and hottest areas in the Sahara and southern African savannahs and deserts. The catchments of the Niger and Limpopo and the Oum-er-Rbia are partly located in these zones of the most extreme temperature increase. The Upper Blue Nile is located in regions with a lower but still very distinct warming. Here temperatures rise between 4°C and 6°C whereas the coastal zones show generally the weakest lower heating.

For precipitation, the model agreement is considerably lower. The Niger basin can be divided in an area with negative precipitation trends in the headwaters of the river in the west, and a positive trend in the eastern part. The longitudinal trend intensifies eastwards, and in the headwaters of the Benue tributary in Cameroon most models agree in a distinct precipitation increase. The Upper Blue Nile is located in the inner tropical belt where at least 80% of the models agree in the positive precipitation trends. The precipitation trend for the Limpopo basin is negative with a high agreement in the western part of the basin, where most of the rainfalls.

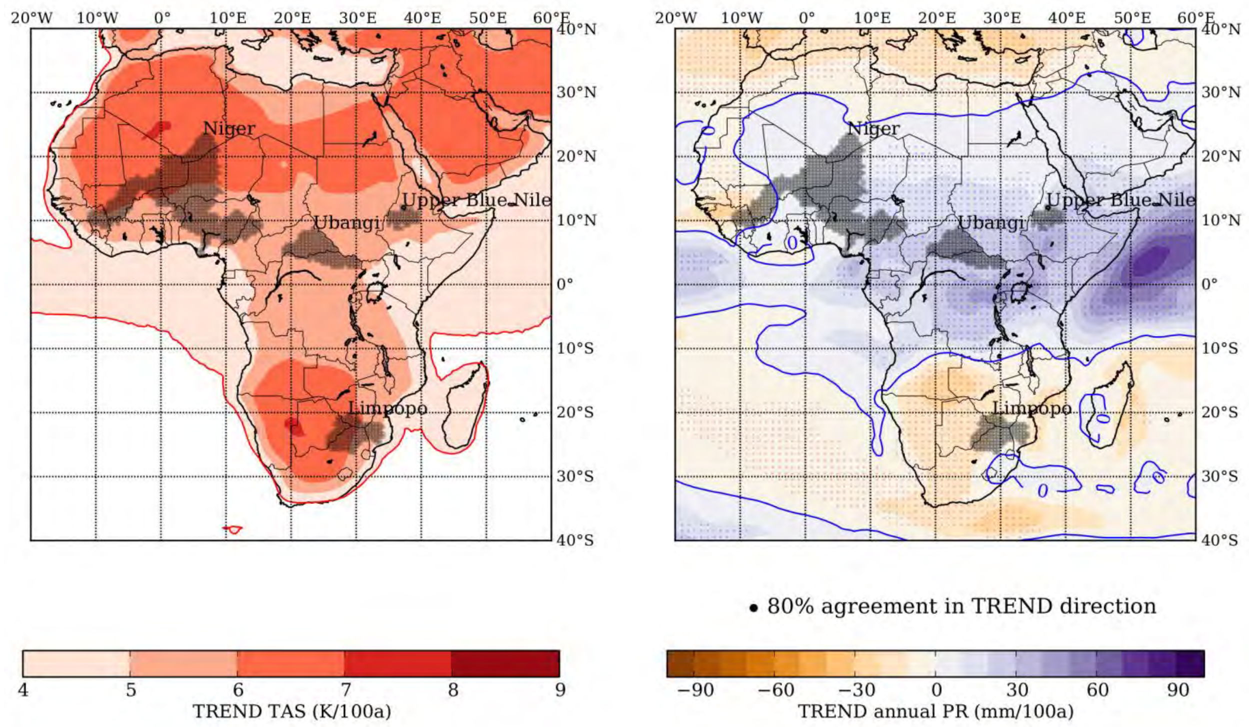
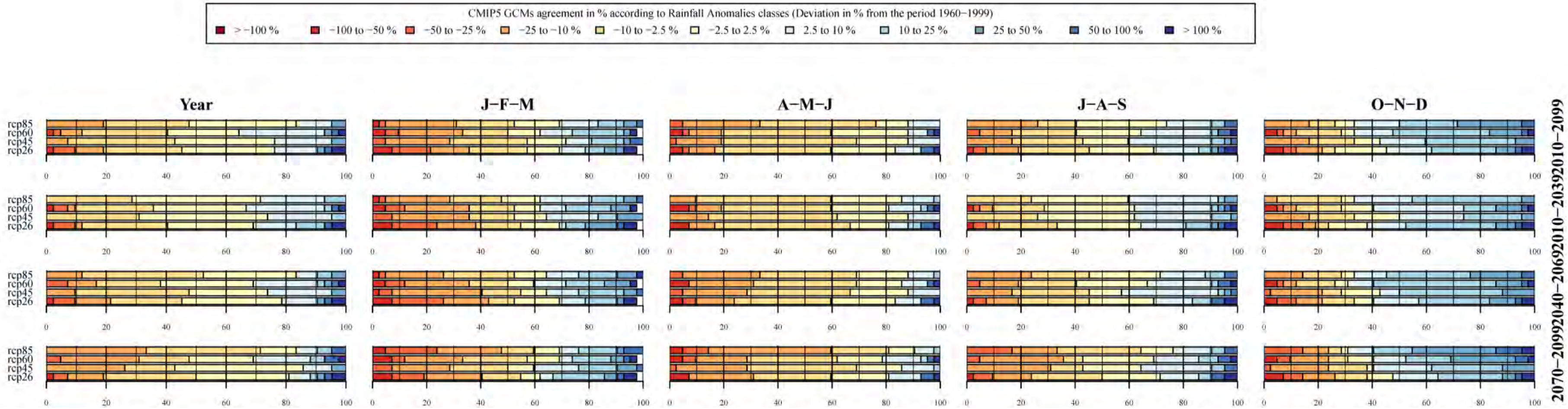


Figure 15: Mean temperature (left) and precipitation (right) trends over the African continent for 19 CMIP5 models from 2006-2100 for RCP 8.5. For precipitation, an agreement of direction of trend of 80% or more of the models is marked with a dot.

Next page, the two next figures summarize the agreement for the given CMIP5 GCM models in term of annual and seasonal rainfall anomalies (baseline period 1960-1999) for the Niger River Basin and the Upper Niger Basin (Top and Bottom set of figures). The outcomes are given for the period 2010-2099 as a whole and per thirty year periods for the four RCP scenarii according to 11 classes of rainfall anomalies. This plot also includes the available sub-runs for each of the GCM. Among all those dimensions, it shows the large spread of rainfall projections from the latest state of art in the Niger river basin region.

According to those results, the assessment of climate change in West Africa cannot only rely on coarse-grid global general circulation models (GCMs). With a typical grid-box size in the range of 150–400 km, GCMs cannot account for the regional heterogeneity of climate variability and change and, hence, are not suitable for producing climate projections at the regional to national scale needed to assess impacts and devise adaptation policies. (Lebel et al., 2000) Practically, all impact studies in the sector of African food security, ecosystems and water resources require fine-scale climate information (Paeth et al. 2011). Therefore, different dynamical, statistical and combined approaches can be used to downscale coarse-grid data sets from GCMs to the regional and local scale in order to account for the effects of complex topographical, land-use and other fine-scale forcings.

Paeth et al. (2011) review the recent progress in dynamical and statistical downscaling approaches for West African precipitation and perform a regional climate model (RCM) intercomparison using the novel multi-model RCM data set from the Ensembles-based Predictions of Climate Changes and Their Impacts (ENSEMBLES) and African Monsoon Multidisciplinary Analyses (AMMA) projects. The results reveal that some important systematic errors still persist in present-day RCMs over West Africa. In addition, the spread of the twenty-first-century rainfall projections is large, even when the RCMs use the same lateral boundary forcing fields. Paeth et al. (2011) suggest that both the model errors and the internal model physics and dynamical processes can contribute to determining the simulated changes. These findings indicate that the skill of RCMs in West Africa can and should be further improved.



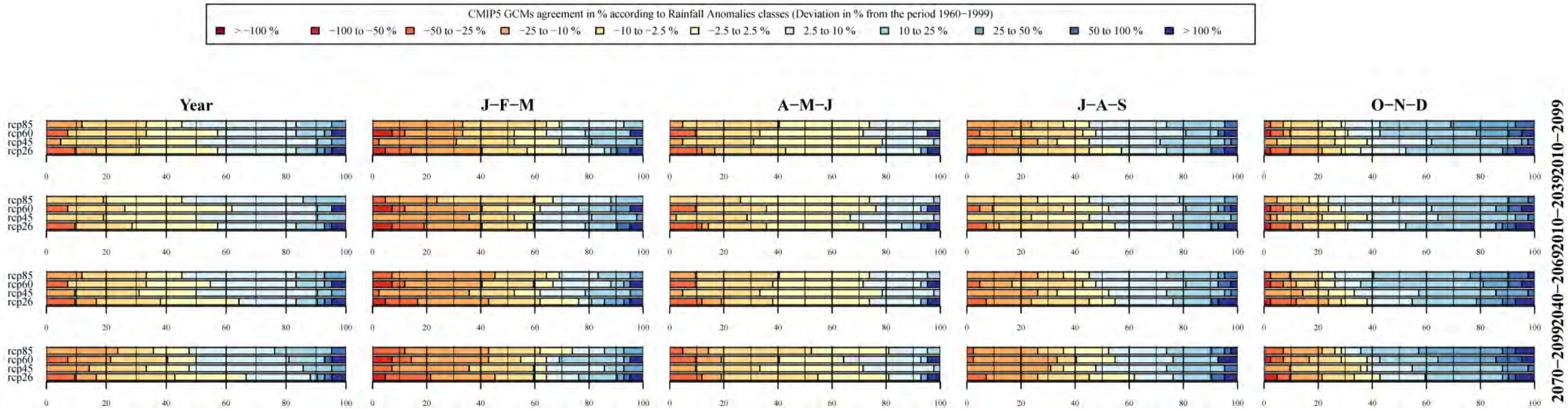


Figure 16 Whole Niger Basin (top) and Upper Niger Basin (bottom) CMIP5 GCMs agreement on annual and seasonal long term precipitation trends.

In this regard, the inception of the new international project Coordinated Regional Climate Downscaling Experiment (CORDEX), which have Africa as its first priority focus region, will provide a common framework for inter-comparing and evaluating RCM simulations and uncertainties and producing an ensemble approach with a new generation of climate change projections over West Africa. But as CORDEX is still at the early stage of data analysis (see next sub-section), an ensemble of bias corrected and downscaled Earth System Models from the Inter-Sectoral Impact Model Intercomparison Project, is also assessed in the course of the DEWFORA project.

2.3.2 CORDEX

The COordinated Regional climate Downscaling Experiment **CORDEX** is an ensemble of multiple dynamical and statistical downscaling models considering multiple forcing GCMs applied as pilot phase to Africa (http://cordex.dmi.dk/joomla/).

This product is still as an early stage and is then unfortunately out of scope for the DEWFORA project for hydrological application as the data deliveries of most of the models were shifted to 2014. However, preliminary analyses of CORDEX climate products are conducted by Peter Hoffmann from PIK. Comparative analyses are presented in this section between the ESM CanESM2 (Canadian Earth System Model 2 from CCCma (Canadian Centre for Climate Modelling and Analysis)) and the RCMs CanRCM4 (Canadian Regional Climate Model 4 from CCCma) or RCA4 (Rossby Centre regional atmospheric model) from SMHI (Swedish Meteorological and Hydrological Institute) both used with CanESM2 entries.

The Figure 17 shows the difference of resolution for the annual precipitation in 1950 between a GCM (CanESM2) and a RCM (CanRCM4). Overall patterns are similar in both resolution revealing higher precipitations close to the coast and in the northeast. However, the southeast shows two precipitation hotspots in the high resolution, where only one is visible in the low resolution. The objective is now to investigate if finer resolution allows capturing more physical drivers of the West African monsoon.

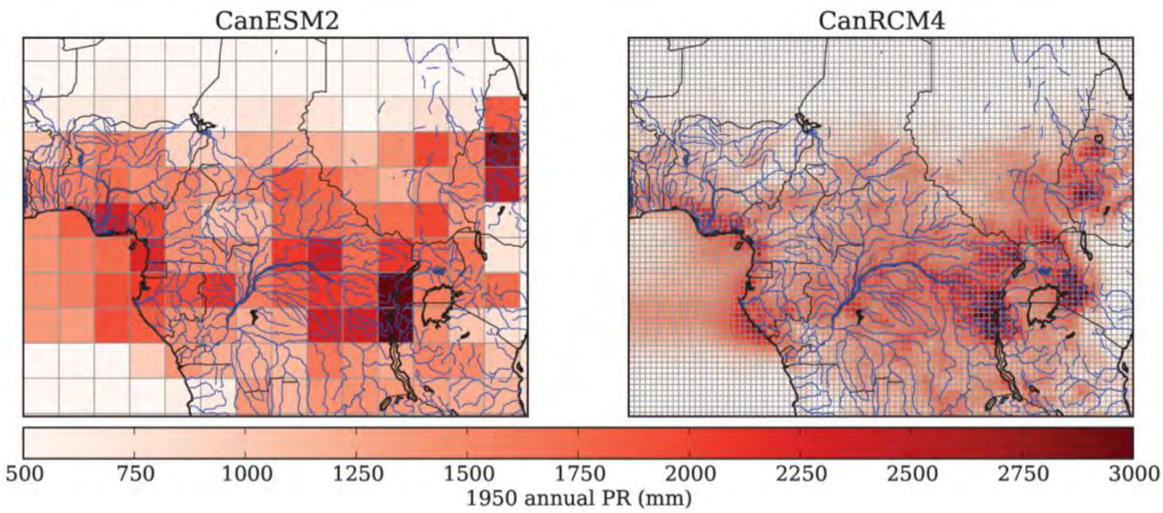


Figure 17 Two different resolutions for global (left) and regional (right) model of Central Africa

The Figure 18 shows side to side the mean daily temperature and precipitation in Africa for the period 1981-1991 and then the respective bias between the Watch Forcing Data, CanESM2 and SMHI-RCA4 (using CanESM2).

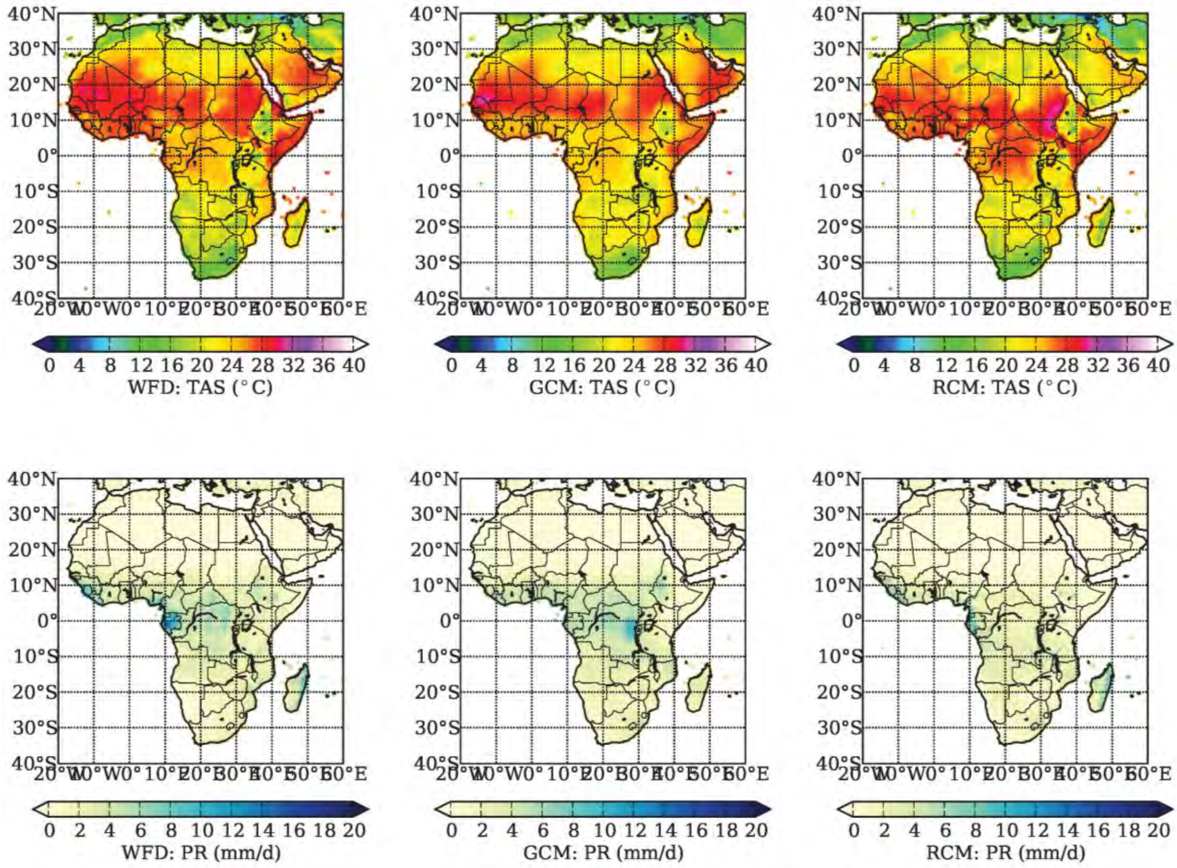


Figure 18: Mean annual temperature and precipitation in Africa for the period 1981-1991 and the respective bias between the Watch Forcing Data, GCM and RCM (from left).

The Figure 19 extends the comparative analysis presenting cumulative probability for Africa using the same climate parameters, period and models. For temperature no difference in cumulative probability is visible between WFD, GCM and RCM. However, days with low precipitation are underestimated by GCM and overestimated by RCM in comparison to Watch Forcing Data. This can be explained by the different resolutions of regional and global models affecting spatial heterogeneous parameters such as precipitation.

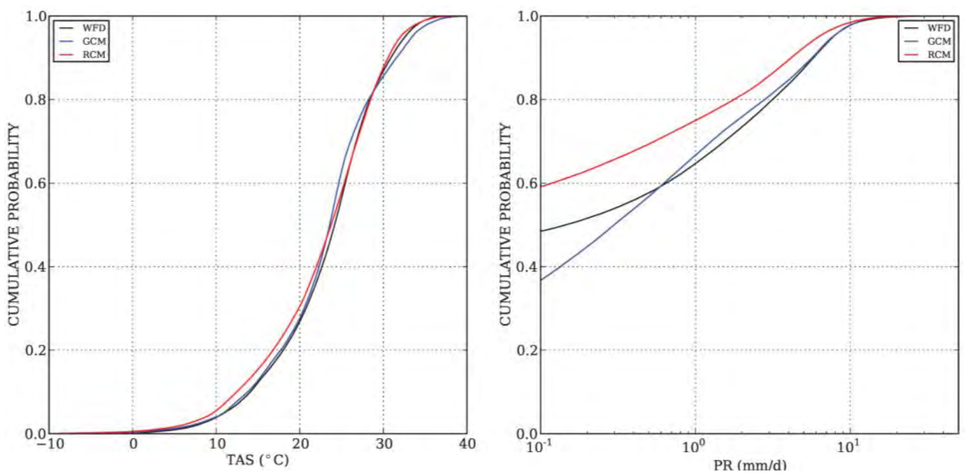


Figure 19: Cumulative Probability for average annual temperature (°C, left) and precipitation (mm/d, right) for Watch Forcing Data, GCM and RCM and for the period 1981-1991.

The Figure 20 shows the division in six sub-regions applied to the African cluster in order to study monthly and annual mean daily temperature and precipitation.

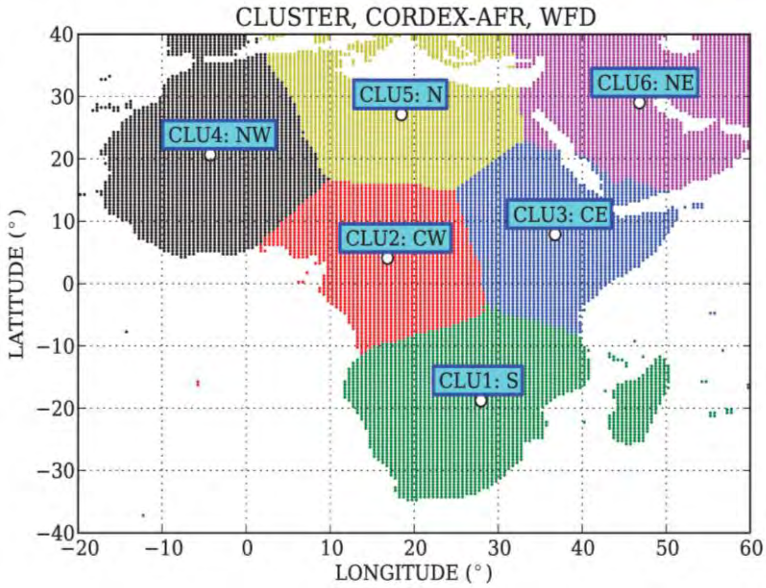


Figure 20: Sub-regions for Africa divided in six clusters (CLU1-CLU6)

The Figure 21 shows for each month and for the 6 sub-regions the mean daily temperature and precipitation for the period 1981-1991 using Watch Forcing Data, the GCM CanESM2 and the RCM SMHI-RCA4 (under CanESM2). The Upper Niger basin, which is located in cluster 4 (NW) shows similar seasonal distribution for temperature and precipitation with a maximum in the middle of the year. In addition, no significant difference can be observed between Watch Forcing Data and RCM and GCM. However, other clusters perform different. For instance, cluster 2 (CW) shows no maximum in temperature over the year, where precipitation reveal two maxima. Whereas models do not differ in temperature, significant difference can be seen in precipitation between RCM and GCM in comparison to WFD.

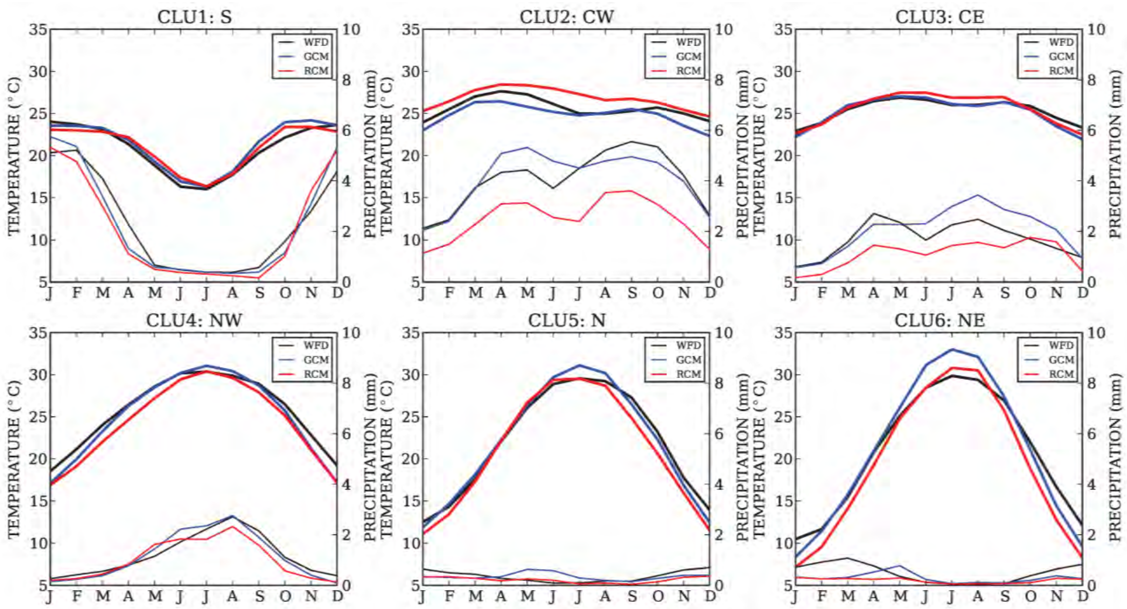


Figure 21: Seasonal temperature (°C) and precipitation (mm) for the six clusters and averaged over the period 1981-1991, each showing Watch Forcing Data, GCM and RCM.

In Figure 22, the respective linear trends for temperature and precipitation expressed in degree Kalvin and in millimeter per century are plotted for the African continent using the RCP 8.5 of the same GCM (blue/black line (left/right plot) and respective RCM (coloured and scaled background). The figure 24 shows the bias correction of climatic parameters from this particular downscaling process. Depending on the region, the operated shift is more or less pronounced but allows preserving regional interannual variability and trends of the GCM on future temperature and precipitation. Figure 23 shows spatial changes on temperature and precipitation trends when applying GCM to a finer resolution. In this particular RCM, the zone of the 6 degrees covers the headwater of the Upper Niger Basin.

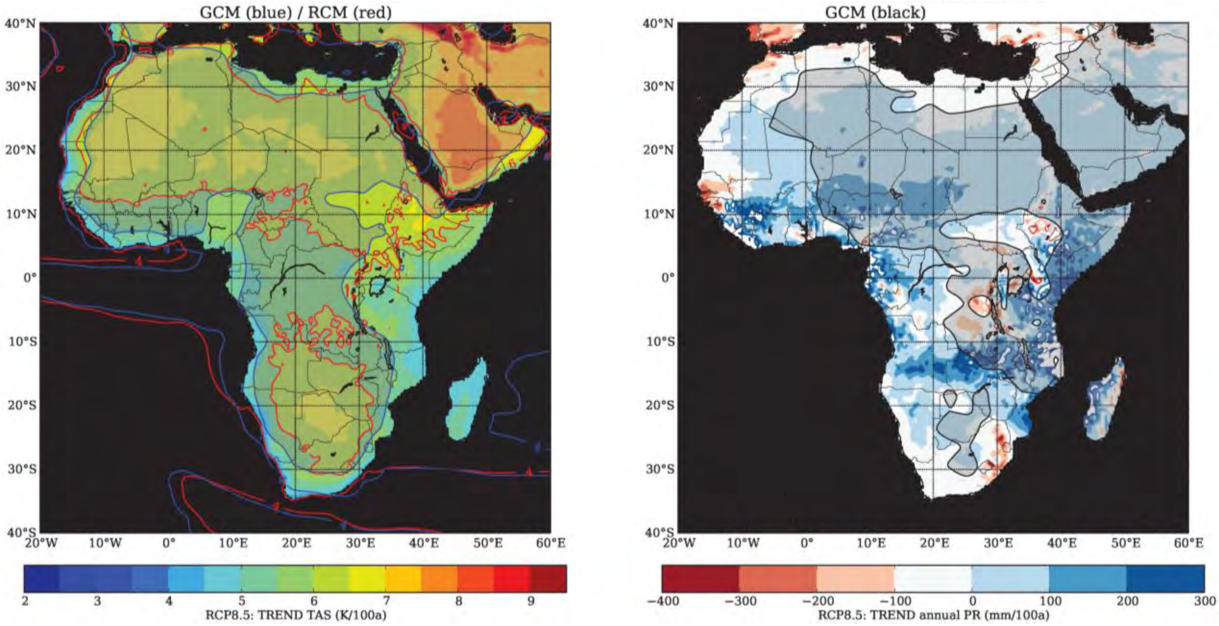


Figure 22: Linear trends per century for temperature (K, left) and precipitation (mm, right) using the scenario RCP 8.5 (background colour) and for given GCM (blue/black lines, left/right plot) and RCM (red lines, left plot)

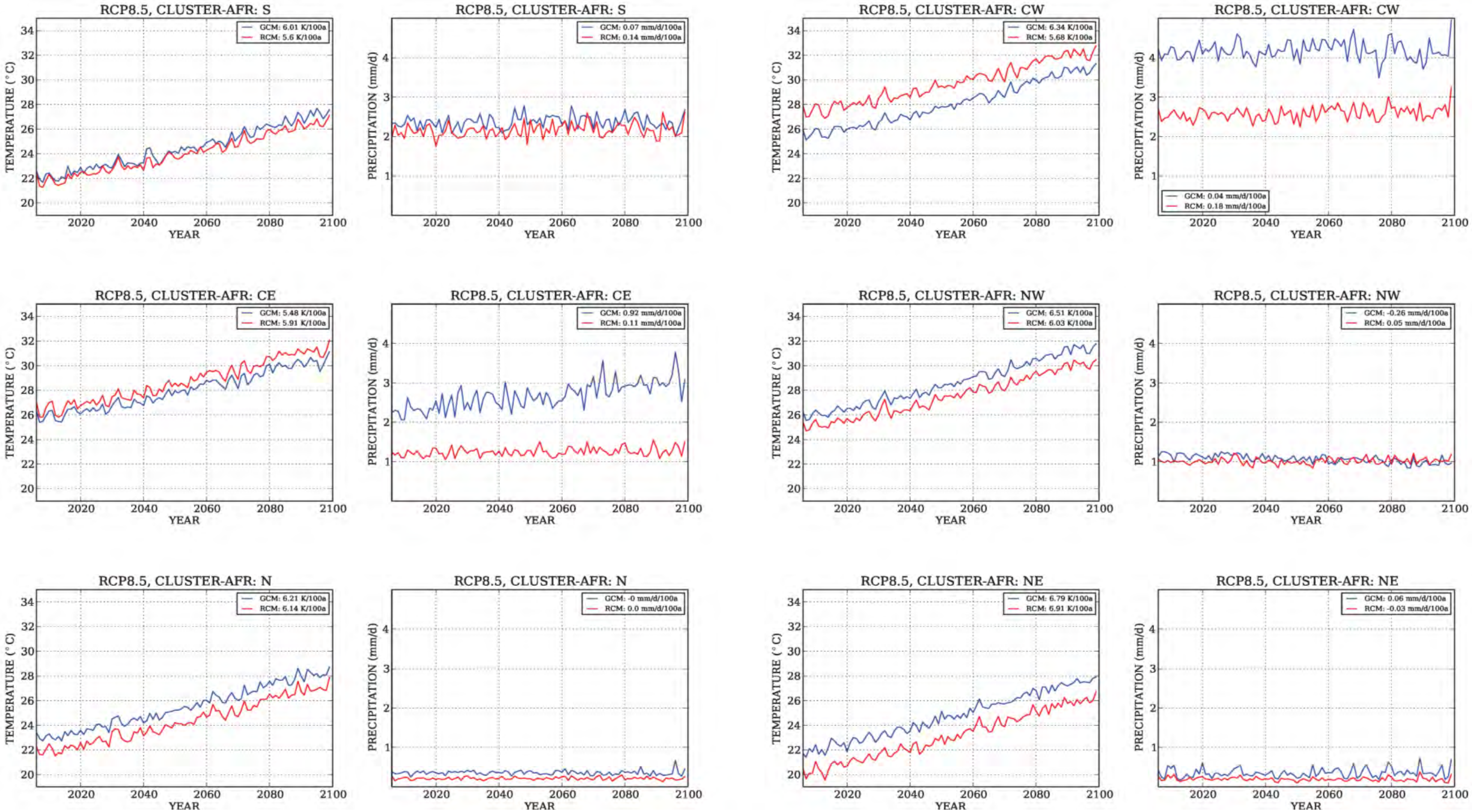


Figure 23: Scenarios (2010-2100) for annual averaged temperature (°C) and precipitation (mm/day) for the six clusters (see Figure 20) and for Global Climate Model (blue) and Regional Climate Model (red), from topleft to bottomright.

2.3.3 ISI-MIP

The **Inter-Sectoral Impact Model Intercomparison Project** is a community-driven modelling effort with the goal of providing cross-sectorial global impact assessments, based on the newly developed climate [Representative Concentration Pathways (RCPs)] and socio-economic [Shared Socio-Economic Pathways (SSPs)] scenarios. Using WATCH forcing data, the ISI-MIP group in PIK downscaled and bias-corrected (Hempel et al., 2013) an ensemble of the five following Earth System Models:

Table 1: Earth System Model used in the ISI-MIP initiative

Model Name	Institution
NorESM1-M	Norwegian Climate Centre, Norway
HadGEM2-ES	Met Office Hadley Centre Earth System Modeling group, England
IPSL-5 CM5A-LR	Institut Pierre-Simon Laplace, France
MIROC-ESM-CHEM	Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute, Japan
GFDL-ESM2M	Geophysical Fluid Dynamics Laboratory of the National Oceanic and Atmospheric Administration, USA

In Figure 24, we use the RCP8.5 scenario to present the difference of monthly mean temperature and precipitation between far projection period (2070-2099) relative to the base period (1970-1999) for 14 ENSEMBLE ESMs (grey dashed lines) and for the five bias corrected ISI-MIP model projections (coloured lines) and the uncorrected ESMs (coloured dashed lines).

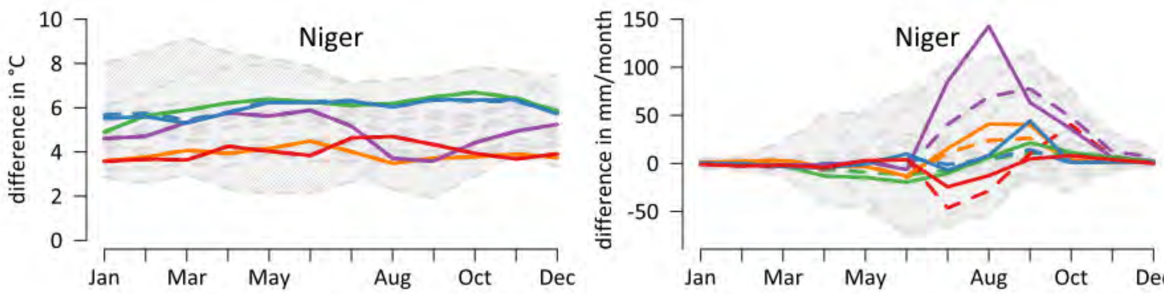


Figure 24: Difference of monthly mean temperature and precipitation between far projection period (2070-2099) relative to the base period (1970-1999) for 14 ENSEMBLE ESMs (grey dashed lines), the five bias corrected model projections (coloured lines) and the uncorrected ESMs (coloured dashed lines).

With the same RCP scenario, the Figure 25 explores the mean monthly precipitation of corrected and uncorrected ISI-MIP climate models and of 14 other CMIP-5 ESMs for the Niger basin during the periods 1970-1999, 2020-2049 and 2070-2099.

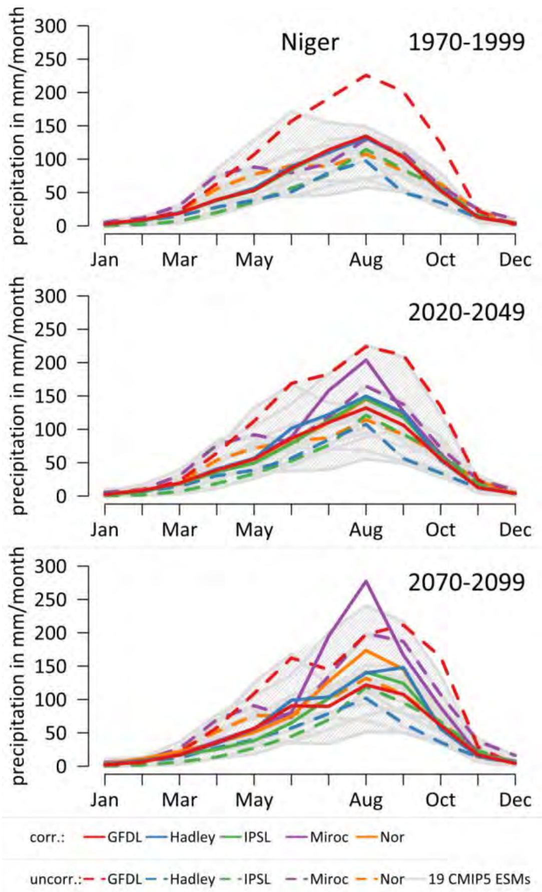


Figure 25: Mean monthly precipitation of corrected and uncorrected ISI-MIP climate models and 19 other CMIP-5 ESMs for the Niger basin during the periods 1970-1999, 2020-2049 and 2070-2099

The Figure 26 shows for one particular ISI-MIP models (NorESM1-M) the effects of bias correction on the Annual mean precipitation from 2010 to 2099 for the four RCp scenario. The historical baseline is also plotted and compared with the annual trend of 20 different precipitation gridded datasets (see previous section for further details).

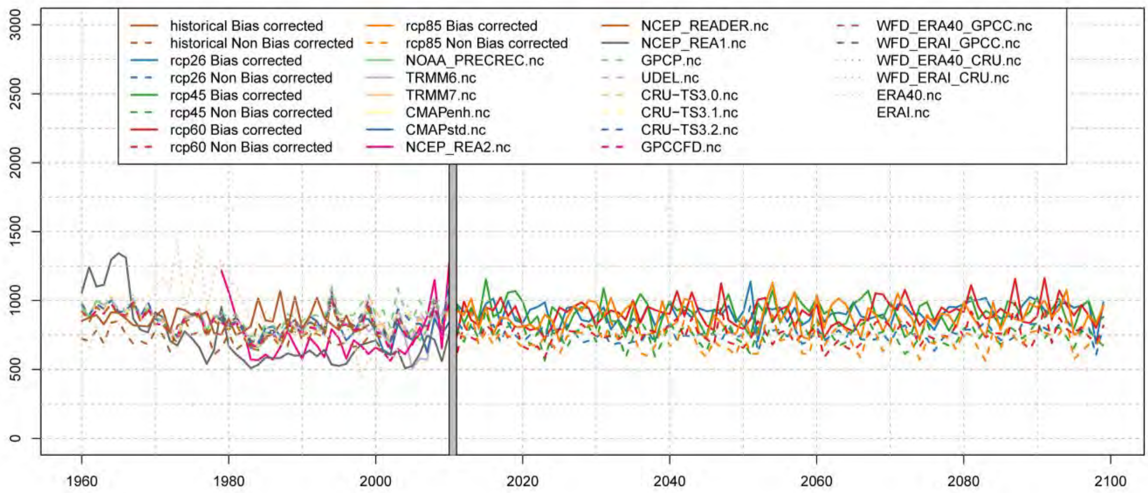


Figure 26: Annual precipitation (mm) in ISI-MIP bias corrected vs CMIP5 non bias corrected GCMs simulation (NorESM1-M_v2).

3. HYDROLOGY: SKILLS, TRENDS AND UNCERTAINTIES IN SIMULATED HYDROLOGICAL DROUGHT PATTERNS

3.1 RIVER BASIN CHARACTERISTICS AND MANAGEMENT

3.1.1 The Niger River basin

(a) Generalities

4200 km long with an active watershed 1.5 million km² shared by nine countries (Benin, Burkina Faso, Cameroon, Côte d'Ivoire, Guinea, Mali, Niger, Nigeria and Chad), the Niger River is the third largest river in Africa after the Nile and the Congo and the largest in West Africa. The population of the basin is estimated at over 110 million people who live mainly on agriculture, livestock, fisheries and various other production activities directly or indirectly related to water resources.

The Niger basin is located approximately between latitudes 5 ° and 22 ° N and longitudes 11° W and 15° E (Figure 27). The basin is shaped like a boomerang, which reflects the unusual trajectory of the flow of the river, as well as the geological history of the region. The Niger River has its source in the continental part of Daro Mountains (in Guinea) which reaches 1068 meters. Then it flows in a north-east to the Inner Niger Delta. Once at Tossaye (Taoussa), the river turns south-east axle, and describes the Niger Bend, and flows towards Lokoja Nigeria, where it receives the waters of its largest and most important tributary: the Benue River. From there, the wider Niger goes directly to the south and empties into the Gulf of Benin via a network of effluents in the Niger Delta in Nigeria (also called terminal delta). The river flows over 4100 km in total, making it the third longest river in Africa. The catchment area of the Niger covers a total area of 2,170,500 km ² (about 7.2% of the land area of Africa) but only 1,400,000 km ² actively contributes to the surface runoff of the river. Due to the flow of the river path, the Niger basin cuts across all major climatic zones of West Africa.

Figure 27: The Niger River Basin. Source: BRL and DHI, 2007a)

The basin is conventionally divided into five different bioclimatic zones based on the types of temperature and vegetation and their characteristics, as well as the total amount of rainfall it receives annually. These climatic zones include the area of the Guinean forest or the Equatorial transitional zone of the tropical belt area, Sudanese savannah zone, semi-arid and savanna of the Sahel belt and the desert region (Figure 27). The main climatic variables, namely precipitation, temperature, humidity and evaporation, show gradual changes as and when it penetrates inland from the coast. The generation of runoff and rainfall reflects the bioclimatic regime. The rainfall varies from more than 500 to 1500 mm per year in the delta terminal in Nigeria and the southern tip of the headwaters of Guinea and Nigeria/Cameroon to almost zero in the desert area and large parts of the Middle Niger and the inland delta.

The basin is also conventionally divided into five hydrographic regions, namely: Upper Niger, the inland delta, the Middle Niger, Benue and Lower Niger. Basin characteristics are derived from Zwarts et al. (2005) and Andersen et al. (2005). Climatological data are based from Willmott and Matsuura (2001) and hydrological measurement from archives of DNH´s gauge measurement collected by Wetlands International.

Upper Niger: The Upper Niger Basin is formed by networks of Upper Niger itself and the Bani River. At the Markala dam, upstream of the inland delta, the Niger River flows over a distance of about 1000 km and covers a catchment area of 131,472 km^2. Over the period 1970-2005, the annual flow of the Niger River at Koulikouro leaving the watershed of 115,375 km2 was 1044 m^3/s, approximately 285 mm/year. The average surface annual rainfall in the upstream surface of Koulikoro for the period was 1426 mm/year, with a runoff coefficient of 20%. The potential evapotranspiration upstream Koulikoro reached 1483 mm/year, while actual evapotranspiration over the period is estimated at 946 mm/year. It therefore seems an unexplained gap closure of nearly 200 mm/year in the water balance of the Upper Niger.

The basin of the Bani River is characterized by a much flatter topography than that the rest of the Upper Niger hydrographic region. The watershed of the river Douna covers 100,464 km^2. An average annual rainfall of 1041 mm/year is recorded since 1970, a 15% reduction in rainfall of 1255 mm/year recorded in the period before 1970 (1951-1969). In addition, over the same periods, the annual runoff decreased by 66% from 225 mm/year (1951-1969) only 76 mm/year (7.6 MdMC/year). This decrease in precipitation is one of the main causes of the reduction of 30 to 40% of the flow although other factors, including changes in land use, irrigation, and other facilities for the development of water resources, may have caused further reductions of flow in this basin. Therefore, the flow rate is increased from 18% before 1970 to 7% after 1970. The average post-1970 of the actual evapotranspiration was estimated at 892 mm/year, which indicates a moderate unexplained gap closure of nearly 75 mm / yr in the water balance of the Bani River.

The inland delta: Located just upstream of the Inner Niger delta , the Office du Niger operates a network of large-scale irrigation that deviates 7% of post-1970 rate of Niger (2.7 MdMC/ year) for irrigation 82,000 ha of rice and sugarcane during the rainy season and about 20,000 ha of rice, sugarcane, horticultural crops and other crops during the dry season. The inland delta extends between Segou and Timbuktu approximately 425 km, taking essentially a direction SW to NE. It is an immense alluvial floodplain and gently sloping with an extensive network of tributaries and shallow lakes plain. The altitude difference between the input and the output of the delta is only 8 m, which leads to a slope of about 2 cm/km and a major flood. Since 1956, the flooded area varies between 8,000 and 25,000 km2. Therefore, a flood peak takes about three months to cross the inland delta. Since 1970, the average flow entering the inland delta is approximately 1.200m^3/s (38 km^3). Since 1970, the loss of water by evaporation in the interior delta represents an average of 40-45% of the inflow (they have become more important over the years with the increase in flow), and since 1970, the rate leaving the inland delta to Timbuktu is an average of 23 km^3.

The inland delta is of considerable economic and ecological importance and is inhabited by about one million people. This number increases during periods of drought with the influx of people affected by this and seeking refuge in the inland delta. Nearly 2 million head of cattle and about as many sheep and goats also attend the delta annually. The annual fish production may exceed 100,000 tons in wet years.

The Middle Niger: The Middle Niger is part of the river which runs from Timbuktu to Malanville at the border between the Republic of Niger and Nigeria. Thus, the Middle Niger extends widely in the Sahel savanna and the arid Sahara region. Much of this sub-basin is hydrologically inactive and the Niger River does not receive runoff from the left bank between Timbuktu and Sokoto State in Nigeria. The right bank of the Middle Niger receives the waters of several tributaries that contribute largely to the inflow of the Niger River along this section. Since 1970, these tributaries are contributing about 2-3 km^3, which compensates for evaporation losses and deductions in this region. The Niger River encounters two types of flooding in the region. The first spill of abundant water, called white flood occurred in August or September as a result of precipitation and erosion in the basin of the Middle Niger. The second elevation, called black flood begins in December with the arrival of the inflow from upstream, delayed by withholding water, mitigation of flood and sediment loss in the inland delta.

The basin of the Benue River: The Benue River rises in the mountains of Adamawa in Cameroon which reaches an altitude of just over 1440 m. At its confluence with the Niger in Lokoja, the Benue extends about 1,400 kilometers long and covers a catchment area of 330,000 km^2. Between 1970 and 1995, the average discharge measured Umaisha was 91.6 km^3, a decrease of 22% compared to an average of 117 km^3 before 1970. The annual precipitation fell only 9% from 1266 mm/year before 1970 to 1160 mm after 1970. Therefore, the relationship between changes in flow and changes in rainfall is about 2.5 (considered the elasticity of precipitation flow value). The Benue River extends over an area largely alluvial. It receives significant water tributaries, including the Gongola, the Katsina Ala, etc.

Lower Niger Basin: The Lower Niger is part of the river that flows mainly at Nigeria, Cameroon and Chad. It consists of two parts: the basin of the Benue and Niger itself, which flows from the border between Niger and Nigeria at the mouth of the river. The Kainji Dam, the largest dam on the Niger River, is located on this section, and is the main hydroelectric plant in Nigeria with an installed capacity of 760 MW. Downstream of Kainji is the second Jebba hydroelectric plant, with an installed capacity of 578 MW. In Lokoja, the Niger and Benue joins the river takes a southerly direction to go into the Gulf of Benin through the Niger Delta (Delta terminal). From 1970 to 1990, the combined average annual flow of the Niger and Benue (measured in Onitsha) was 159 km^3, the rate has declined by nearly 22% compared to the period before 1970 as a result of drought and likely changes in land use. Technically, the Niger Delta is part of the Lower Niger. It covers an area of 20,732 km^2 and a coastline of 450 km long. Rainfall received by the delta vary between 1800 and 2000 mm/year.

The Niger Basin has huge economic and social development advantages, including agricultural and hydropower plant, fisheries and pastoral activities but repeated droughts during three decades, combined with population pressure on natural resources, lack of investment and concerned with the preservation of effective environmental policies have led to a rapid deterioration of lands and waters on which the adverse effects are, among others, silting and flooding by floating plants, fragile ecosystems and recurring conflicts between users, etc.,

The Niger Basin Authority (NBA)

In 1964, countries sharing the basin decide on the creation of the Niger River Commission in 1980 which became the Niger River Authority Basin (NBA), whose purpose is to promote cooperation among member countries and ensure integrated development of the basin by the development of its resources, particularly in the areas of energy, water resources, agriculture, livestock, fisheries and aquaculture, forestry and logging, transport and communications and industry

The Convention establishing the NBA (revised in 1987) assigns the following objectives:

- Harmonize and coordinate national policies for the development of the basin's resources;
- Participate in development planning through the development and implementation of an integrated development plan for the basin;
- Promote and participate in the design and operation of facilities and joint projects;
- Provide supervision and regulation of all forms of navigation on the river, its tributaries and sub tributaries in accordance with the "Act of Niamey";
- Participate in the formulation of requests for assistance and the mobilization of funds for the studies and work necessary for the development of the basin's resources.

Faced with the increased degradation of the basin's resources and meet the growing needs for food security, energy and development, members of the NBA decided in 2002 to develop and implement a SHARED VISION for: "Strengthening cooperation between Member States and take full advantage of the basin's resources through a consensus process, negotiated and accepted by all. He it comes to the basin, an area of sustainable development for present and future generations "2004, will be the turning point with the signing by all nine (9) Heads of State and Government of the member countries of the NBA the "Paris Declaration" outlining the principles of management and good governance for sustainable development of the Niger Basin.

In May 2005 in Abuja, Nigeria, a Special Session of the Council of Ministers of the NBA adopted the following three priority areas:

- the development of socio-economic infrastructure;
- the preservation of ecosystems;
- the participation and capacity building of stakeholders (governments, civil society, private sector ..)

This new momentum of the Members is to make the Niger River, an area of harmonious basin resulted after multiple studies and meetings, the adoption in April 2008 (at the 8th Summit of Heads of State and Government) the Plan of Action for Sustainable Development (PADD) at horizon 2025 together with a priority investment program includes the construction and rehabilitation of several major water infrastructures in the basin. This is among other things, the proposed Fomi dam in Guinea, the Taoussa dam project in Mali the Kandandji dam project in Niger and the rehabilitation of the Kainji and Jebba in Nigeria. In addition to these large hydraulic infrastructures, several projects and programs including capacity building of the actors have been prepared and adopted.

Niger River Basin, Water Resources and Climate Change

The historical hydrologic trends of the Niger River, the rainfall, runoff (defined as rainfall minus evapotranspiration) and river discharge fluctuate significantly between seasons (by a factor of almost 1:100). The average and dry season river flows have fluctuated considerably between years. For example, the average discharge of the river at Koulikoro in Mali in 1982-1993 has been only 45% of the discharge in 1951-1970, a period of high river discharge. However, in 1994-2008 it increased again to 67% at that level.

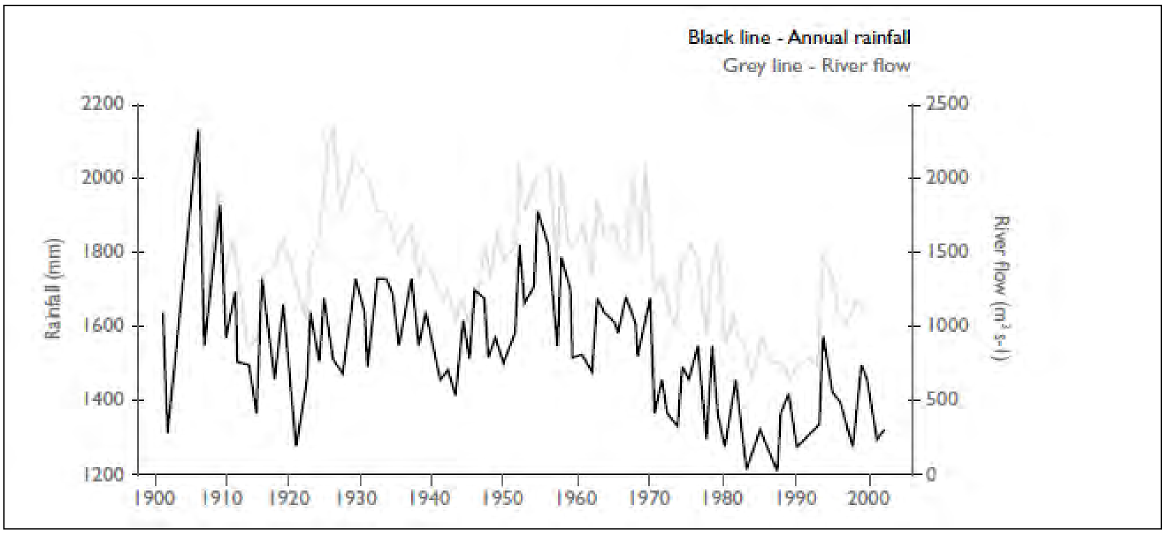


Figure 28: Annual Rainfall and river flow of the Niger River at Koulikoro in Mali from Conway et al., 2009

The climatic future of the Niger Basin remains uncertain, but climate change is expected to have a key influence on water resources and human security through its impact on climate variability and extremes (Zwarts, 2010). There may be other indirect influences of climate change, for example higher temperatures leading to greater demand for water. A very high degree of climatic variability is expected to continue and may well become more pronounced on seasonal, annual and decadal timescales (Brooks, 2004). Even though, there is no consensus amongst the Global Climate Models (GCMs) over the future climate of West Africa in general and the Niger Basin especially, the region's experience so far high level of vulnerability to impacts of climate change; ranging from recurrent droughts (Niger River zero flow of 1984 and 1985 at Malanville and Niamey (Benin and Niger respectively) to recurrent floods (flooding at Niamey 2012).

During the recent years, few publications have been released about the impact of climate changes on the water resources of the Niger River Basin

BMZ and KFW, 2010 reported that, an analysis of six locations in the Upper and middle Niger Basin using the World Bank's climate change knowledge portal (version 2005) shows that projections by 20 GCM models are not consistent concerning the direction of change (increase or decrease) in rainfall and runoff. The tool does not project changes in river discharge. It would thus be premature to make investment plans on the basis of either lower or higher water availability in the Upper and Middle Niger basin. However, the same study concludes that human activities with direct environmental impacts and population growth play a decisive role. In the 50-year period considered by the climate models, the population of the basin is likely to increase by about 250% from about 8 million in 1999 to more than 20 million in 2049 assuming a slowdown in birth rates. Even if one assumes that only half of the increased population (about 9 million people) will depend on agriculture, fisheries and livestock, this will put tremendous pressure on already stressed natural resources. For example, it would increase water abstraction by about 6 km³ per year. This impact compares to the impact of climate change, which – in an assumed worst case of a 20% reduction in river flows compared to the low average flow of 1970-1998 – would correspond to 6.5 km³.

Marisa Goulden and Roger Few, 2011 in a study entitled "climate change, water and conflict in the Niger River Basin" reported that the initiatives to support adaptation cannot afford to address climate-related problems alone. The uncertainty surrounding future climate conditions in the basin, adaptation goals, targets and modes of implementation need to flexible, rather than being locked into one particular view of what is happening locally, nationally or sub-regionally. In the Niger River Basin, the authors do not find a traceable, direct impact of climate stresses alone causing conflicts. The report offers examples of both good and deficient adaptation occurring at a range of scales, form local to national. At the regional and national level, water resources management and other government policies do not sufficiently consider the uncertainty and growing climate variability on long-term notes the report.

Oguntunde et al., 2012 studying the impact of climate change on the Niger River Basin hydroclimatology reported that the elevated of Greenhouse Gas would produce a drier climate during the rainy season and a wetter climate during the dry season. A warmer climate over the Niger River basin in all months was projected. Highest temperature increase of 3°C occurs in 14°N in May and June, and the smallest increase of 0.5°C occurs below 8°N in wet-dry season transition period. Evaporation reduces during wet season and increases during dry periods. Humidity increases by 2% in the dry season, but decreases by 2-4% in the wet season. The results suggest that under enhanced Greenhouse Gas, local evaporation will contribute to less moisture to atmospheric moisture and precipitation over the basin. Projected changes in rainfall and streamflow for the Upper Niger and Benue sub-basin are significantly different during the wet season.

Juddy et al., 2013, reported that for the entire basin holistically and sub-basin wise, an increase of temperature by a value <3.79% over the entire basin; while rainfall decreased by a value < 10% and a river flow decreased is in the range of 14.24%. Further results show that the increasing trend in temperature is at the rate of 0.001°C/month and 0.02°C/year over the entire basin. While climate models differ however, modeling done by the authors in the study reveals the high level of varying sensitivity of the Niger River Basin, particularly the lower Niger sub-basin to the changing climate, which justifies the various experiences of impacts of climate change in the region, there is discernible evidence of climate change in the Lower sub-basin (Nigeria), adjudged by the observed changes in the onset and cessation of dates of seasonal rains and the presence trends in the hydro-climatic series. It is further observed that part from the Sahel region, Sudano-Guinean region or the humid portion in the lower Niger sub-basin are also vulnerable to the changing climate and its impacts. Also, a future drier climate is expected to impact negatively on the runoff and invariably on the available water resources for the entire basin, mainly for the Lower Niger. Hence, proactive and aggressive management strategy is seriously needed to match any unfathomable impact.

Finally, the sustainable Development Action Plan (SDAP: BRL and DHI, 2007a/b, PADD Phase1/2, NBA) assesses climate risks to water resources and related sectors development of the Niger Basin Short (2030), medium (2050) and long (2070) term, and quantifying climate risks based as well on the information delivered in the climate change knowledge portal of the World Bank (source: http://sdwebx.worldbank.org/climateportal). The present portal is based on GCMs from the Coupled Model Intercomparison Project Phase 3 (CMIP3). According to the study the projected impacts of climate change on flows of the Niger Basin impacts are moderate. Several climate projections for the Niger Basin until 2050 have identified a minor increase in average precipitation (2%). Two out of three climate models project minor to moderate rainfall increase and 90% of the analyzed climate projections (34 of 38) for the 21st century suggest changes ranging from - 6% to 7% for 2050. All GCMs project significant increases in temperature, generally between 1°C and 3°C (an average of 2.10°C or 8% of the average of 26.6°C in the 20th century) to 2050. The Potential evapotranspiration and crop water needs will increase by 5% by 2050, according to estimates. The result of mean flow projected essentially is constant in the 21st century with an average of only 2% below the average of the 20th century, and a 25% probability of a 10% decrease to a minimum and 20% maximum. Eighty-five percent (85%) analyzed a series of models and project changes in flow between 18% and 10%. Based on the GCM predictions, the decreased flow by 20% in 2050 and beyond has been identified as the worst hydrological scenario.

Of the three major components of the SDAP (namely: a) development of socio-economic infrastructures, b) resource protection and conservation of ecosystems of the basin and c) capacity building and involvement of stakeholders in IWRM), the construction of dams Fomi (Guinea), Taoussa (Mali), Kandadji (Niger) dams and the rehabilitation of the Kainji and Jebba (Nigeria) dams seem to be the priority for NBA and the nine member countries. The implementation of this component to NBA and member countries seems to be one of the best ways to adapt to climate change in the Niger River Basin. Therefore all development scenarios in the basin of the Niger River in the short, medium and long term the NBA take the scenario: Fomi-Taoussa-Kadandji as a baseline. The latter is tested against the impacts of climate change.

Different climate change scenarios were tested and their impacts on different sectors of socio-economic activities (production hydropower, irrigated agriculture season against, navigation) and ecological (environmental flows has Markala and Malanville) in the Niger River Basin for the years 2030, 2050 and 2070

- Scenario1 : Reduction of -10% of the river discharge
- Scenario2 : Reduction of -20% to- 40% of the river discharge
- Scenariro3 : Reduction more than -60% of the river discharge

According to the study, it is alos expected that domestic water demand would triple, the demand for water for irrigation is multiplied by five, the water demand for livestock decreases of 3.5% (2005) to 1.4% (2025-2050), water demand for industry and mines have not been considered. It is expected that controlled irrigation pass 265,000 ha (2005) to 1.5 million ha in 2025/Max. The total water demand (including controlled flooding) will increase from 5 billion cubic meters per year in 2005 to 26 billion cubic meters per year 2025/Max

In summary, potential impacts of climate change on water demands are:

- An increase in the ambient temperature of 2°C in 2050 should cause an increase in evaporation water ponds of about 5%.
- The crop water needs increase accordingly while the river flows decrease slightly
- The climate change could impact on the demand for water in the dry season for irrigation and evaporation from reservoirs, mainly due to increased evapotranspiration (~ 5%).
- The annual increase in the demand for irrigation water would be about 1.5 billion m3 per year, with 0.5 billion m^3/year increase evaporation losses from reservoirs.
- Modest impact on water demand of crops due to climate change can be offset by adaptation measures aimed at improving irrigation efficiency which is relatively low at present.
- In the short and medium term, low irrigation efficiency could pose a major problem, larger than the future impacts of climate change on water demand for irrigation for an unchanged rainfall.

The report pointed out the sensitivity of selected sectors to climate change under different scenarios with the option FOMI-TAOUSSA-KADANDJI dams:

- Irrigated agriculture is the least sensitive to climate changes, due to dominant priorities in the allocation of water
- The impacts of climate change on hydropower, navigation and flood the Inner Delta are projected to be low (<10% reduction) to moderate (<20% decrease). There is a probability of 25-35% by 2050 that these sectors show decrease of performance by more than 10% (moderate risk).
- The minimum environmental flows in the Inner Delta and Middle Niger are more sensitive to climate change and increased irrigation water demands, and cannot be maintained without adaptation measures.

3.1.2 The Upper Niger Basin and the inner Niger Delta

The "Water for Food and Ecosystems" project funded by the "Dutch Partners for Water" was the framework for the development of decision support system for the management of the scarce water resources of the Upper Niger and the Inner Niger Delta of the Niger River Basin. For this purpose four scenarios were used:

- Scenario1 : Without Selingue and Markala dam
- Scenario2 : Without Markala and with Selingue
- Scenari33 : With Markala+Selingue
- Scenario4 : With Markala+Selingue+Fomi

The impact of these different scenarios were tested on levels of water resources of the river, the extension of flooded areas of the Inner Niger Delta, production of rice, fish and livestock, navigation, biodiversity (migratory waterbirds)

The results obtained are as follows:

Hydrology: A reduction in the flow of the river in September respectively 117, 357 and 1035 m^3/s due to the scenarios, 2, 3 and 4. Reduced river levels respectively 7, 15 and 45 cm respectively due to scenarios 2, 3 and 4. A reduction in flood areas of the Inner Niger Delta 300, 600 and 2200 km^2 respectively due to scenarios 2, 3 and 4.

Rice production in the Inner Niger Delta: they are respectively +10, +5 and -40% for scenarios 2, 3 and 4.

Fish production in the Inner Niger Delta: Scenarios 2, 3 and 4 cause losses of fish production of 6, 13 and 37%.

Livestock production in the Inner Niger Delta: Respectively the production of livestock in the Inner Niger Delta is negatively impacted by the scenarios 2, 3 and 4: -1, -2 and -9%. **Navigation (transport boats) in the Inner Niger Delta:** Navigation is affected by the scenarios respectively 2.3 and 4 in the proportions of 3, 2 and -1%

The types of habitats and biodiversity in the Inner Niger Delta: With the exception of Scenario1, the other scenarios of water resources management have ecological impacts on natural habitats (habitat loss) affectation of habitat qualities by the loss of their functions. The artificial habitats (artificial wetlands) created through the different scenarios are low biological values compared to natural wetlands. The reduction surfaces or loss of habitat leads to increased mortality of migratory waterbirds and make them more vulnerable to hunting pressures

Economic analysis: The cost-benefit analysis of different scenarios showed that there is a transfer of welfare downstream populations (Inner Niger Delta) to upstream population (Upper Niger). The people of the Inner Niger Delta are becoming increasingly vulnerable to the effects of climate change and the effects of upstream dams. As a result there is a strong migration from the DIN upstream.

3.2 IMPACTS OF PROJECTED CLIMATE CHANGE AND UPSTREAM RIVER MANAGEMENT ON THE FLOOD REGIME WITH SWIM

3.2.1 Introduction

The Niger River basin experiences a high seasonal and interrannual climate variability with severe dry episods affecting the regional food security and socio-economic development as well as the conservation of wetlands and semi-arid ecosystems. It results in an increasing competition and conflicts for water and natural resources between vulnerable local stakeholders (rainfed and semi-controlled irrigation farming, nomadic pastoralism, traditional fisheries) and steers national investments with the construction of dams and diversion channels for the development of hydropower energy and fully governed irrigated agriculture.

In this context, the use of tailored hydrological model can improve drought preparedness contingency planning and strategic decision-making at river basin and community scales.

This section aims at presenting long term hydrological projections in the Upper Niger Basin and the Inner Niger Delta under upstream river basin management scenarii. The Soil and Water Integrated Model (SWIM) projects long term hydrological drought pattern using ISI-MIP Earth System Models. Calibrated with Watch Forcing Data, SWIM incorporates different scenarii of main operationnal water managements of the river basin (reservoirs and water uptake from irrigation schemes) as well as an inundation module accounting for flood propagation processes in the Inner Niger Delta. Based on water level time series, the skill of the statistical model OPIDIN (Outil de prédiction des Inondations du Delta Intérieur du Niger) is assessed for mid term responses and improvements in the dissemination of the forecast information from the early warning system platform are expounded.

3.2.2 SWIM development, setup and calibration

(a) SWIM

Many hydrological models with different degrees of physical background exist; each adopting different approaches to reproduce the spatial heterogeneity and the hydrological processes in a catchment. For this case study the eco-hydrological watershed model SWIM (Soil and Water Integrated Model) had been chosen. The eco-hydrological model SWIM is a daily continuous-time, semi distributed catchment model for the coupled hydrological / vegetation / water quality modelling in mesoscale watersheds (Krysanova et al., 1998, 2000a, 2000b, 2005). SWIM simulates crop and vegetation growth, nutrients dynamics (nitrogen and phosphorous), hydrological and erosion processes at the river basin scale (Figure 29). Hydrotopes or hydrological response units (HRUs), respectively, are the core elements in the model. The HRUs are considered as units with same properties (soil and land use/cover) regarding bio-physical processes. The model is connected to meteorological, land-use, soil, vegetation and agricultural management input data. It was developed from SWAT (Soil and Water Assessment Tool) version ’93 (Arnold et al., 1993) and MATSALU models (Krysanova et al., 1989) for climate and land use change impact assessment on hydrology and water quality.

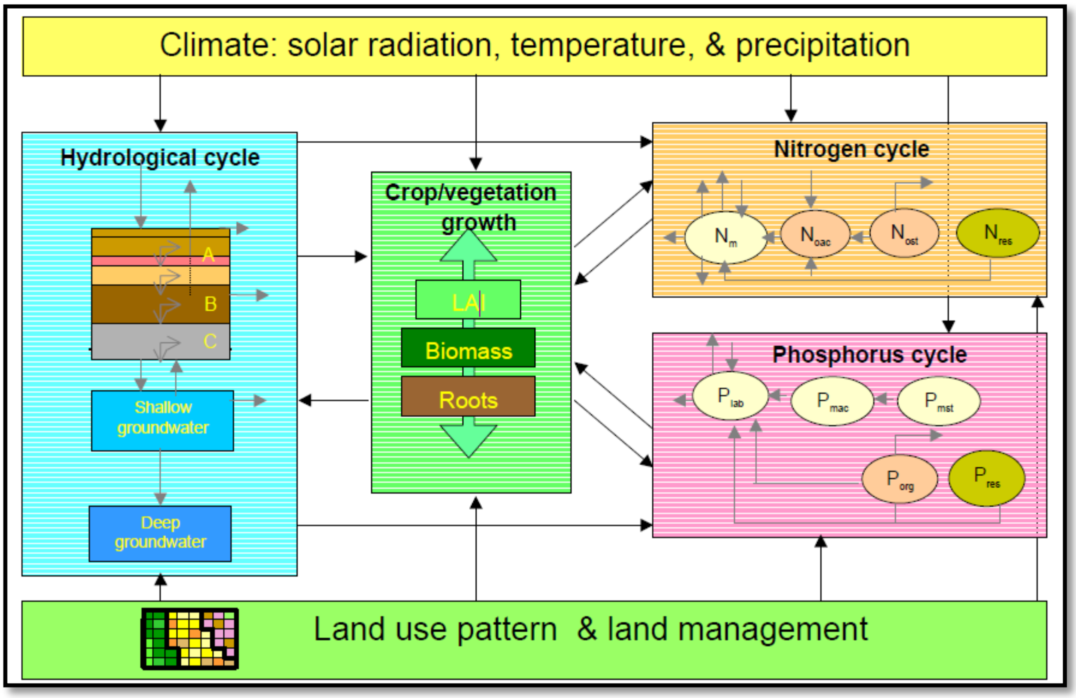


Figure 29: Simulation process diagram for the SWIM model in Krysanova et al.,2000a

The hydrological module is based on the water balance equation, taking into account precipitation, evapotranspiration, percolation, surface runoff, and subsurface runoff for the soil column subdivided into several layers (Figure 30). The simulated hydrological system consists of four control volumes: the soil surface, the root zone, the shallow aquifer, and the deep aquifer. The percolation from the soil profile is assumed to recharge the shallow aquifer. Return flow from the shallow aquifer contributes to the streamflow. The soil column is subdivided into several layers in accordance with the soil data base. The water balance for the soil column includes precipitation, evapotranspiration, percolation, surface runoff, and subsurface runoff. The water balance for the shallow aquifer includes ground water recharge, capillary rise to the soil profile, lateral flow, and percolation to the deep aquifer.

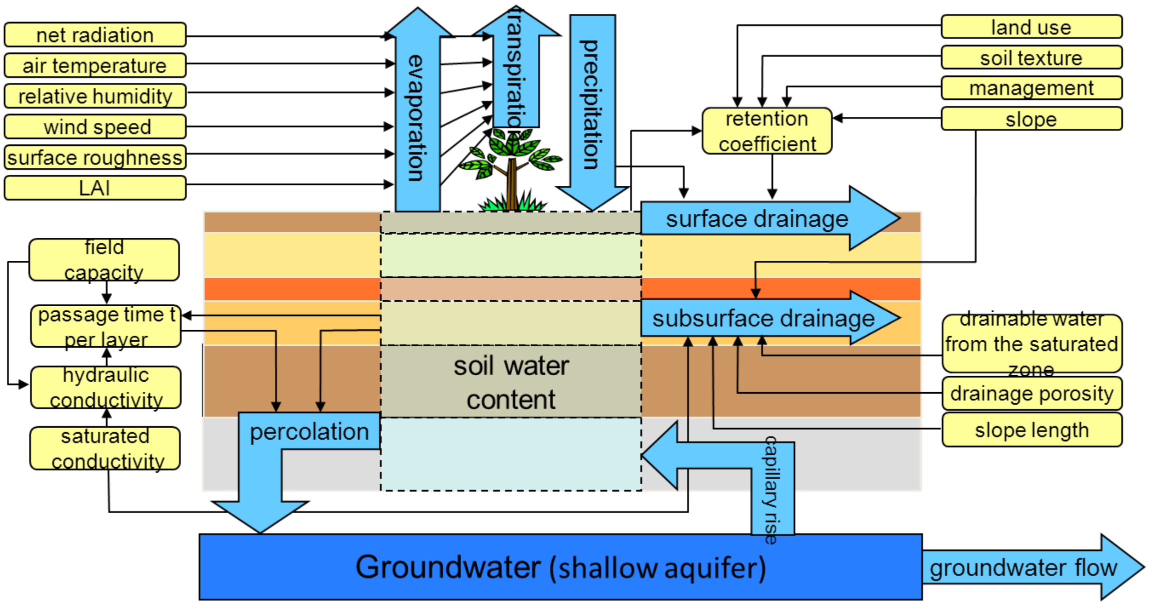


Figure 30: The governing processes in SWIM for the simulation in Krysanova et al., 2000a

- **Reservoir module**

A reservoir module (Koch et al., 2013) was developed and integrated into the SWIM model in order to account for impacts of medium to large dams on river discharge. The model provides three different reservoir management options:

1. Variable daily minimum discharge to meet environmental or other targets downstream under consideration of maximum and minimum water levels in the reservoir,

2. Daily release based on firm energy yield by a hydropower plant at the reservoir (the release to produce the required energy is calculated depending on the water level),

3. Daily release depending on water level (rising/falling release with in- creased/falling water level, depending on the objective of reservoir management).

- **Inundation module**

The inundation module, integrated into SWIM, is required to adequately simulate hydrology of the Upper Niger Basin including the Inner Niger Delta (Liersch, 2011). It simulates the flooding dynamics and release, the flooded surface area, inundation depths, and duration, as well as losses due to evapotranspiration and percolation. An important objective was to develop a simple method in order to keep the complexity and data requirements as low as possible. The basis of the wetland module in terms of data requirements are a digital elevation model of adequate resolution, which mainly depends on the wetland area size, and two calibration parameters (the inundation threshold controlling hru-switching *ind_et*, and the recession constant α for the inundation storages). All other parameters can be derived from the DEM or are model parameters anyway. Potentially, the parameters determining the cross-section geometry could be considered as calibration parameters, because they are a source of large uncertainty when they are derived from a DEM. The inundation module is a semi-explicit process based model. The Inner Niger Delta is divided into sub-basins that respect the routing of the model SWIM. Within the sub-basins and according to a refined digital elevation model, inundation zones are delimited based on the water height and allow to estimate the water volumes stored within the inundation zone and within the ponded area. The flooding simulation encompasses backwater effects, evaporation (water surface), percolation and release (Figure 31).

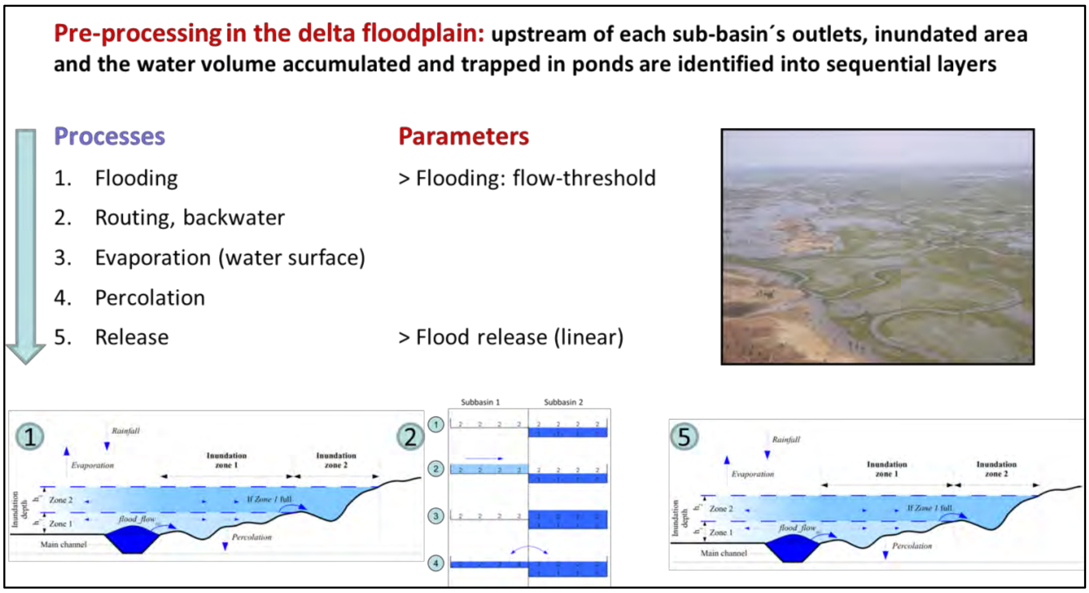


Figure 31: Scheme detailing inundation module processes developed in SWIM

(b) Model Setup

- **Past climate inputs**

Watch Forcing Data derived from ERA40 and bias-corrected precipitation under GPCC was used to setup and calibrate the model. More information on WFD datasets can be found in the chapter 2.1.

- **GIS data refinement and reclassification**

SRTM elevation data (Jarvis et al., 2008) served as input for the delineation of sub-basins. Soil classes are taken from the Digital Soil Map of the World (FAO et al., 2009) and the parameters are derived from the Harmonized World Soil Data Base. Finally, land use data were reclassified according to SWIM standard from Global Land Cover (GLC2000). All GIS data refinement and reclassification are summarized in the table below.

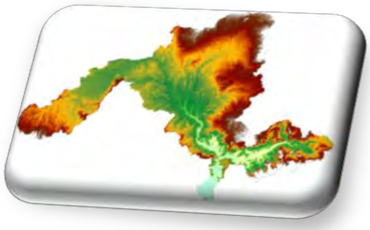
SWIM referencing GIS inputs	Name	Reference
Digital Elevation Model 	SRTM Version 4, 90m resolution by the Shuttle Radar Topographical Mission	http://bioval.jrc.ec.europa.eu/products/glc2000/glc2000.php
Land-use classification 	Global Land Cover 2000	http://bioval.jrc.ec.europa.eu/products/glc2000/glc2000.php
Soil classification and parameterization 	Digital Soil Map of the World	http://www.fao.org/geonetwork/srv/en/metadata.show?id=14116&currTab=distribution
	Harmonized World Soil Data Base v1.1	http://www.iiasa.ac.at/Research/LUC/External-World-soil-database/HTML/index.html
Sub-basin delineation 	**Upper Niger model** Number of sub-basins: ~390 Sub-basin average area: ~1000 km²	**Niger river model** Number of sub-basins: 1923 Sub-basin average area: 1150km²

Table 2: GIS data refinement and reclassification for SWIM setup and parameterization

(c) Model calibration

- **Discharge measurement for calibration**

Discharge data are provided by the Global Runoff Data Centre (GRDC) which works under the auspices of the World Meteorological Organisation (WMO) (hosted by the German

Federal Institute of Hydrology (BFG)). This source is completed with water level information coming from the database archives of Wetlands International. A summary of the inter-annual variability (1960-2001) of monthly mean discharge at different locations in the Niger basin is presented using GRDC dataset in the following Figure.

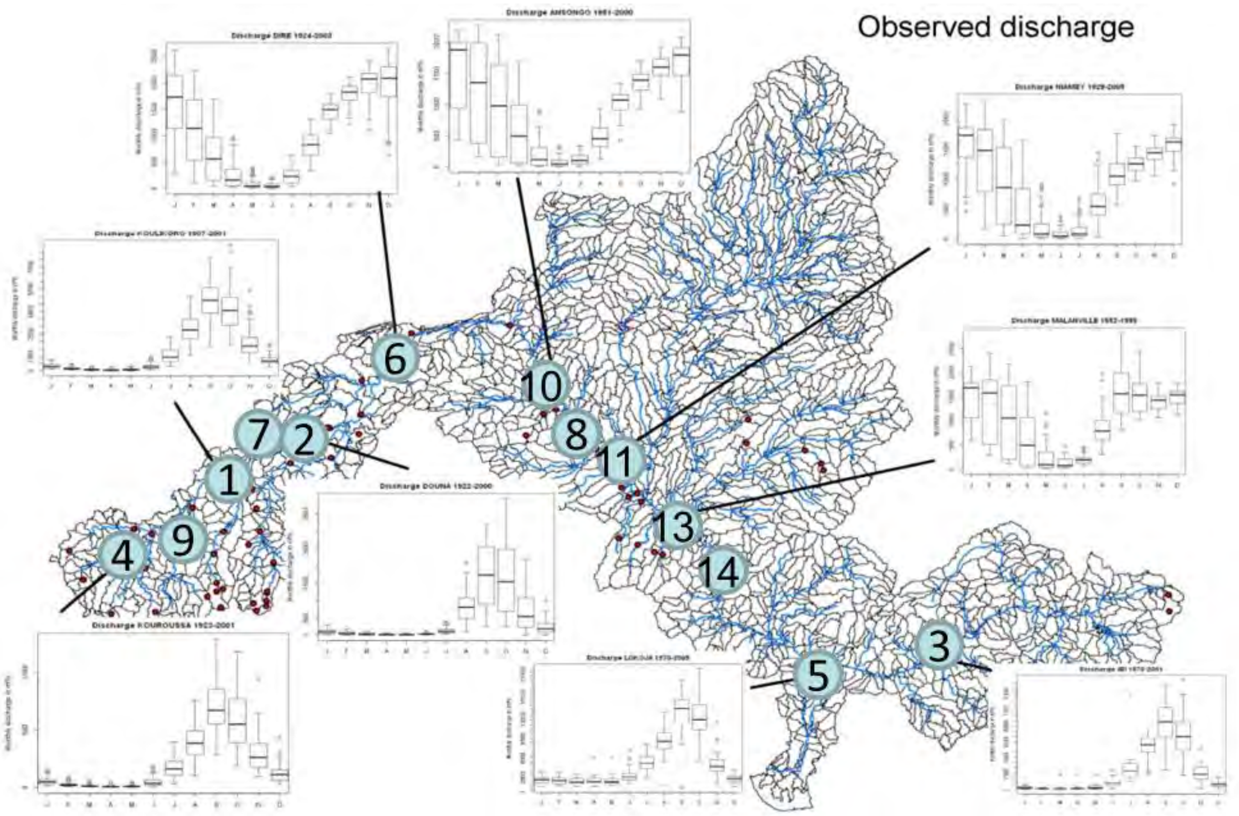


Figure 32: Inter-annual variability (period depending on time series availability) of monthly mean precipitation at different locations in the Niger basin, GRDC dataset

- **Model Calibration Method**

WATCH climate data served as input and daily observed discharge data, provided by the Global Runoff Data Centre (GRDC), were used for calibration and validation. The model PEST (Model-Independent Parameter Estimation and Uncertainty Analysis: http://www.pesthomepage.org/) was used to calibrate and validate the two model setup versions with the sets of parameters presented in the following table. Further details on the selected calibration/validation parameters and the undergoing related processes operated within SWIM can be found in Krysanova et al., 2000a.

Calibration parameters	Description
roc2	routing coefficients to calculate the storage time constant for the reach for the surface flow
roc4	routing coefficients to calculate the storage time constant for the reach for the subsurface flow
sccor	correction factor for saturated conductivity (applied for all soils)
bff	baseflow factor for basin, is used to calc return flow travel time. The return flow travel time is then used to calculate percolation in soil from layer to layer
abf	alpha factor for grounwater. This parameter characterizes the groundwater recession (the rate at which groundwater flow is returned to the stream).
delay	groundwater delay (days). The time it takes for water leaving the bottom of the root zone until it reaches the shallow aquifer where it can become groundwater flow.

Table 3: Summary of the parameters used for calibration in SWIM based on Krysanova et al., 2000a

- **Results of the calibration and validation processes**

A summary of the calibration performance on 14 monitored gauges in the Niger River Basin is delivered in the next table using a daily Nash Sutcliffe coefficient for the given period.

ID	Monitored Gauge	Calibration period	NSE
1	Koulikoro	1964-1974	0.93
2	Douna	1964-1974	0.88
3	Ibi	1975-1995	0.87
4	Kouroussa	1964-1974	0.86
5	Lokoja	1972-1982	0.85
6	Dire	1964-1974	0.83
7	Kirango Aval	1975-1981	0.82
8	Kandadji	1976-1986	0.82
9	Selingue	1965-1975	0.8
10	Ansongo	1968-1979	0.76
11	Niamey	1975-1985	0.76
12	Tossaye	1968-1979	0.75
13	Malanville	1976-1986	0.54
14	Yidere Bode	1985-1995	0.18

Table 4: summary of the calibration performance on 14 monitored gauges in the Niger River Basin

Figure 33 Figure 34 illustrate the performance for the calibration and the validation of the model. For further details, the deliverable 4.7 present in detail all the processes. From 1964 to 1974, the simulated discharge at gauge Koulikoro (Figure 33) fits to the observed discharge reproducing well high peaks and low flow patterns with a respective Nash-Sutcliffe Efficiency (NSE) coefficient of 0.93. During the calibration, the discharges in the Upper Niger Basin were characterised by a natural flow regime not yet affected by the Sélingué dam, which was built in 1982. In the validation period (1982-2000), the Sélingué dam was then also integrated in the model and tested to simulate the management of the reservoir and its effect on the hydrological regime. Therefore, the calibration-validation process enables to analyze the skill of the model to reproduce the hydrological regime under the water management of the Sélingué dam.

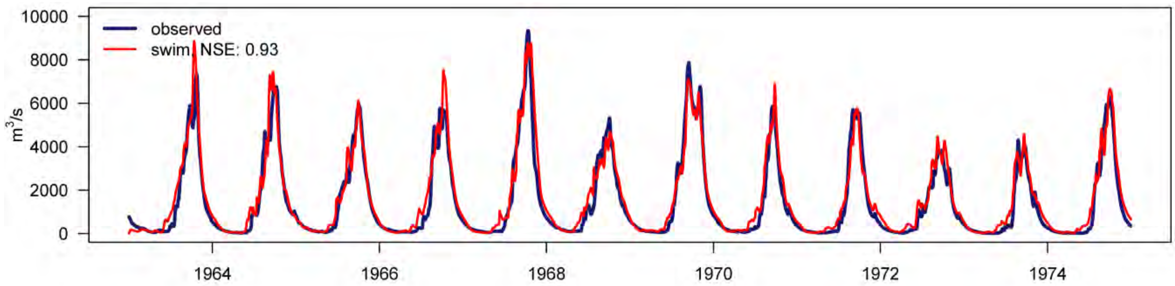


Figure 33: SWIM simulation at the gauge Koulikoro for the calibration period (NSE: 0.93)

Located upstream the Niger Maritime delta, the gauge Lokoja was validated (Figure 34) with a daily Nash-Sutcliffe Efficiency (NSE) coefficient of 0.9 (calibration period 0.85) and a Pbias equal to 2.1.

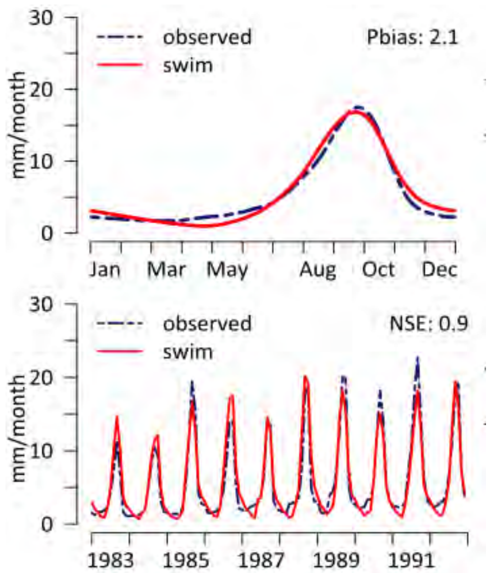


Figure 34: Validation of SWIM at the outlet Lokoja. In top row seasonality of monthly runoff rate in validation period and bias in percent, in bottom row monthly runoff rate in validation period with Nash-Sutcliffe Efficiency

(d) Climate change projections

This section describes rainfall and temperature projections of five to four CMIP5 Earth System Models (ESMs) for the Upper Niger Basin (UNB) in West Africa. These global climate models were downscaled and bias-corrected by the ISI-MIP group of PIK (Hempel et al., 2013) using WATCH forcing data (WFD), a global gridded climate dataset in 0.5 resolution (Weedon et al., 2011). The chapter 2.2.3 is already devoted to present the temperature and precipitation trends of the ISI-MIP climate products.

Figure 35 shows the sensitivity of annual discharge at Lokoja gauge to interannual variabilites of precipitation using a fitted local regression (LOESS) curve over all values

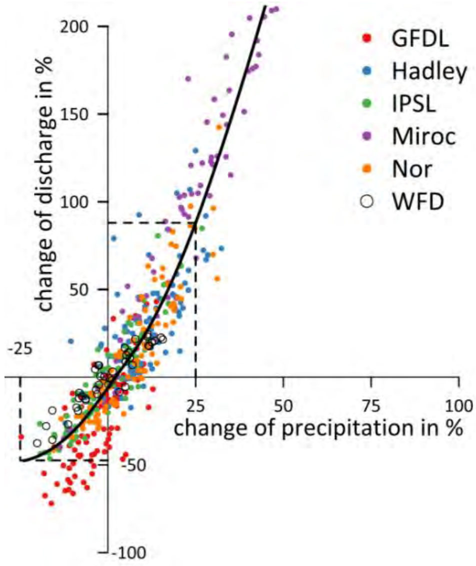
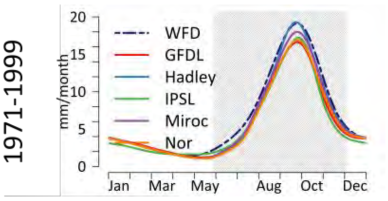


Figure 35: Climate sensitivity in the Niger river basin outlet. Change of modeled annual discharge at Lokoja gauge [percent] per change of precipitation [percent] for 2006-2099 compared to mean of base period 1970-1999 for five climate models in RCP 8.5. Curve shows fitted local regression (LOESS) over all values.

Figure 36 shows the hydrological responses from the five ISI-MIP ESMs for the baseline as well as the changes in discharge in % from the baseline period to close and far future periods. Four of the ESMs show reasonable results in discharge changes when Miroc suffered from instabilities in the incremental downscaling and bias correction process. In regard to these abnormal trends, Miroc model was definitely put aside in the study.



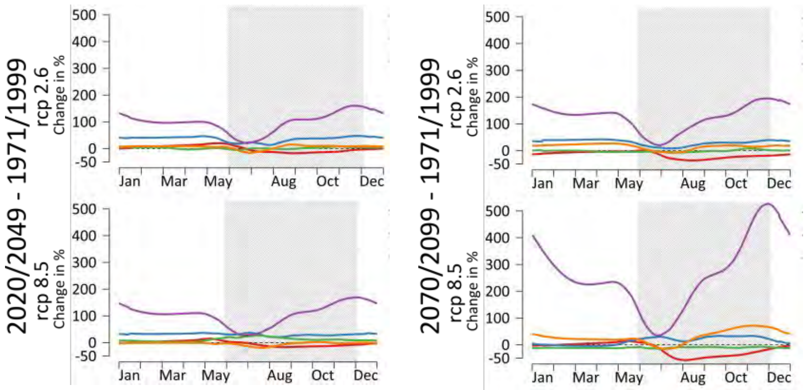


Figure 36: First column: seasonality of monthly discharge at Lokoja gauge for the reference period; second and third column: changes in % of discharge between a near and far scenario period and reference periods for RCP2.6 and RCP 8.5; Rainy season as grey shade.

Various plots and figures (Figure 37 to Figure 44) are presented to visualise climate change signals from two scenarios (RCP 2.6 and RCP 8.5) by comparison of future periods with the reference period 1970-1999 in the Upper Niger Basin. Most figures show results of the multimodel mean. However, two figures for precipitation and two figures for temperature projections show the differences of the projections of these four ESMs individually. Some figures show change signals of annual average rainfall and temperature and some figures and tables show changes at the monthly time scale. We use the two extreme scenarios RCP 2.6 and RCP 8.5 with different underlying assumptions about radiative forcing to show the full range of state-of-the-art climate projections. RCP stands for “Representative Concentration Pathways”. RCP 2.6 is a moderate scenario whereas RCP 8.5 represents an extreme but not unlikely scenario. Climate model assessment was conducted for rainfall and temperature analysis.

Figure 37 shows the multi-model mean of average annual rainfall in the reference period (Left) as a map of the study area. On the middle and the right, it shows the differences of average annual rainfall between the RCP 2.6 and RCP 8.5 scenarios between the reference period in [mm] and the entire scenario periods (2010-2100) which are not differentiated into scenario sub-periods. The yellow polygon represents the catchment of the Upper Niger Basin, the red lines the study areas, and the darkred lines country borders. Colours represent either average annual rainfall or annual rainfall differences (middle and right maps). It first shows that rainfall is unequally distributed in the catchment where the mountainous southwestern regions receive up to 2800 mm/a and areas in the northeast only 200-500 mm/a (study area). Average annual rainfall over the entire area shown in the map is 943 mm. The map shown in the middle indicates that multi-model mean annual rainfall in the RCP 2.6 scenario averaged over the entire period (2010-2100) is likely to increase in the entire area. Average annual rainfall amounts to 1013mm that is 70mm more than in the reference period. This scenario does not show any decrease in rainfall in the entire area. Average annual rainfall over the entire area in the RCP 8.5 scenario (right) is with 1004mm a bit lower than in the RCP 2.6 but still 61mm higher than in the reference period. Noticeable is the change gradient from northwest to the east. Where rainfall is projected to decrease in the west/northwest (not affecting the UNB), it still shows an increasing trend in the UNB, particularly in the northeast of the catchment.

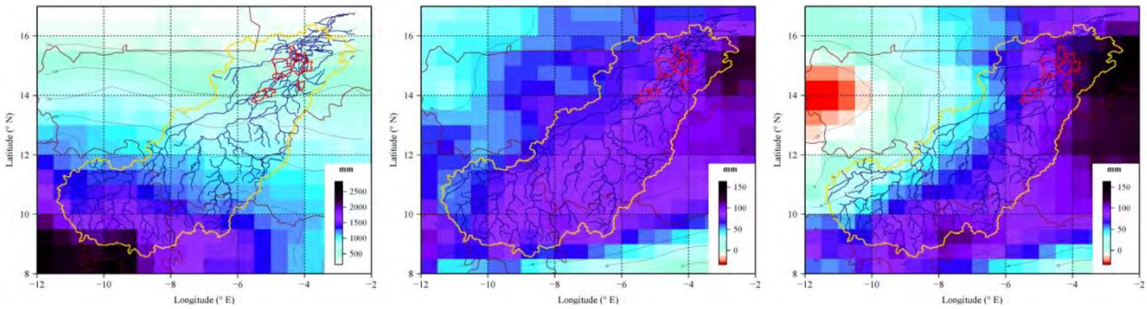


Figure 37: Average annual rainfall for the period 1970-1999 (left) and average annual rainfall differences (2010-2100 minus 1970-1999) with RCP 2.6 (middle) and RCP 8.5 (right) scenario in the UNB expressed in mm: Multi-model mean of four ISI-MIP ESMs

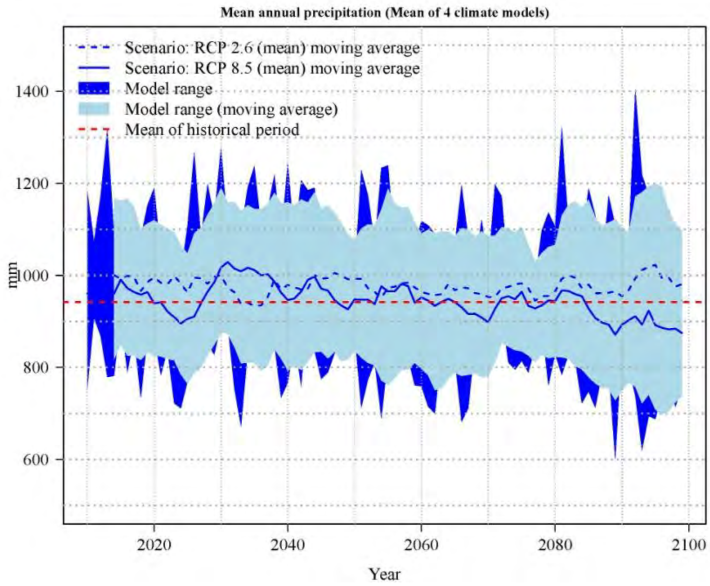


Figure 38: Annual rainfall projections for UNB (2010-2100). Average of four ESMs

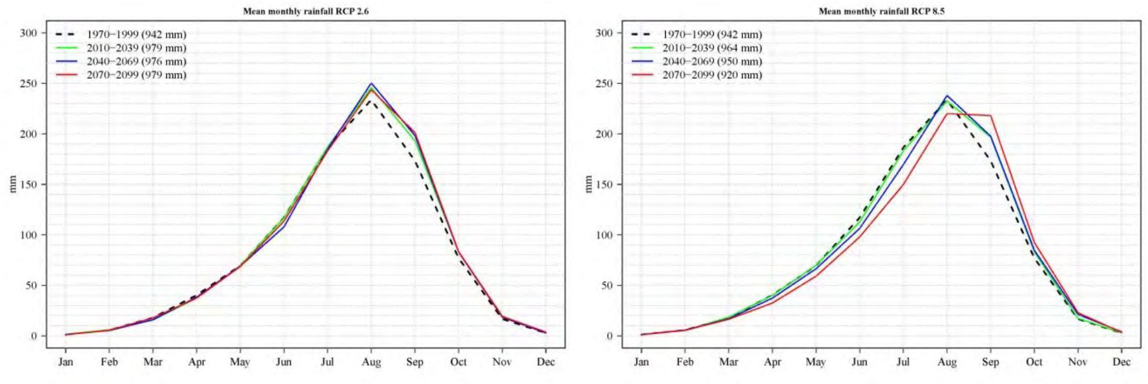


Figure 39: Monthly rainfall projections in mm for UNB (2010-2100) RCP 2.6/8.5 (left/right)

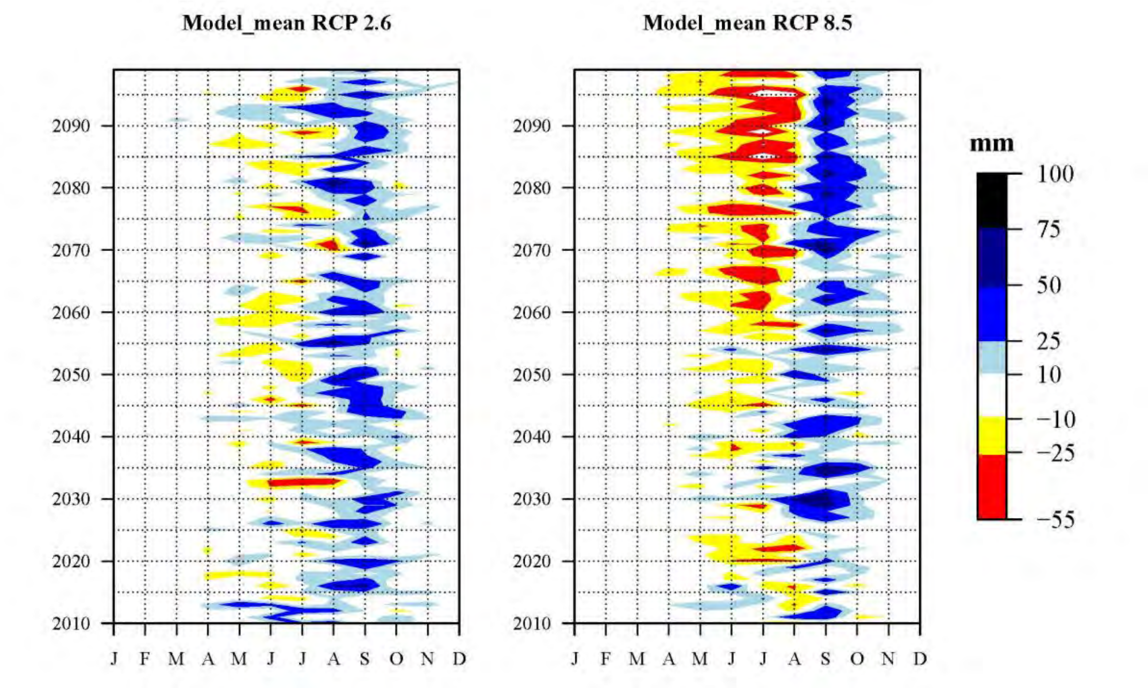


Figure 40: Monthly rainfall anomalies for UNB (2010-2100). Average of four ESMs

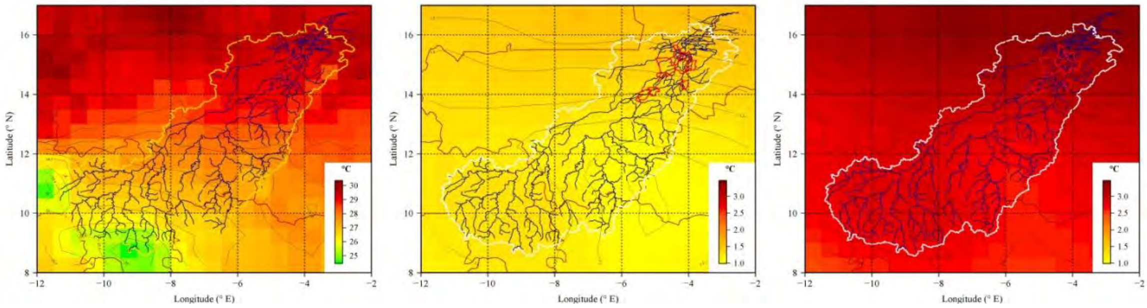


Figure 41: Average annual temperature for the period 1970-1999 (left) and average annual temperature differences (2010-2100 minus 1970-1999) with RCP 2.6 (middle) and RCP 8.5 (right) scenario in the UNB expressed in in ° Celsius: Multi-model mean of four ISI-MIP ESMs

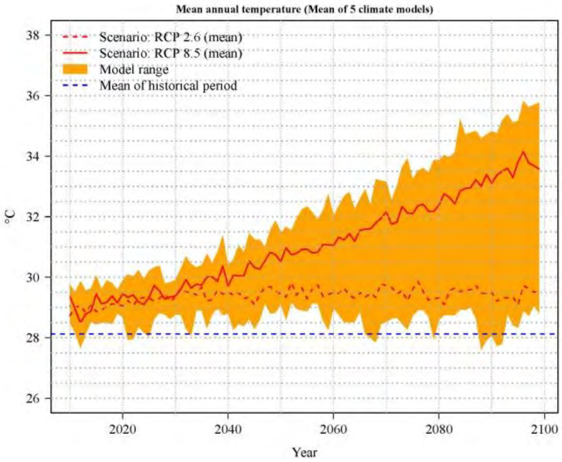


Figure 42: Annual rainfall projections for UNB (2010-2100). Average of four ESMs

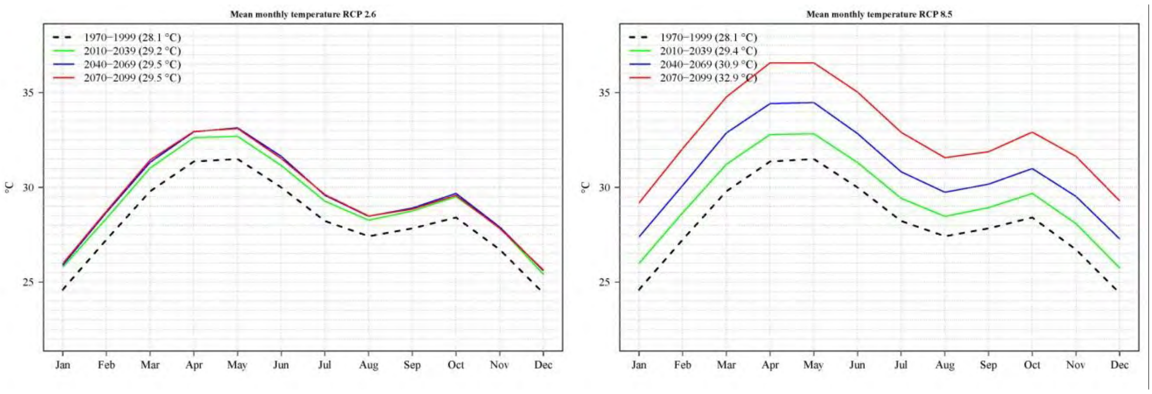


Figure 43: Monthly Temperature projections in ° Celsius for UNB (2010-2100) RCP 2.6/8.5 (left/right)

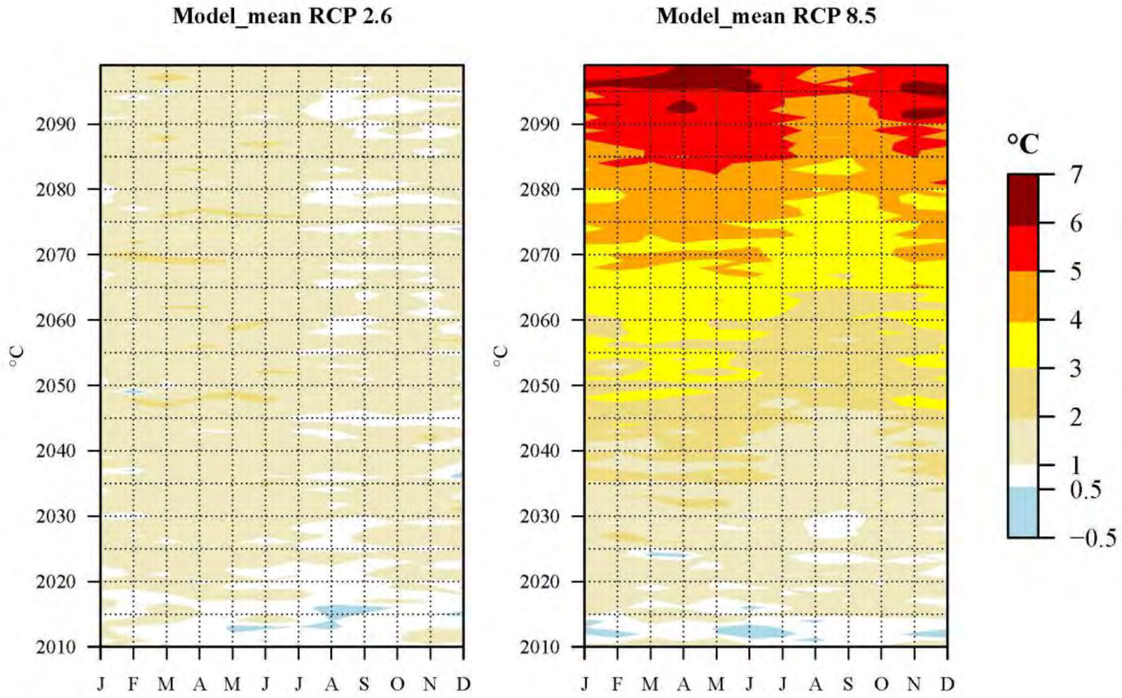


Figure 44: Monthly temperature anomalies for UNB (2010-2100). Average of four ESMs

In Liersch et al. (2005), all regional climate models used for the Upper Niger Basin, project in comparison decreasing rainfall trends by 2050 and 2100 (CCLM). The dynamical models REMO and CCLM project relative annual decrease of -11.6% (REMO A1B), -8.7% (REMO B1), and -9.2% (CCLM) by 2050. The projected temperature trend for this period is between 1.5C and 2.1 °C (REMO and CCLM). The projections of the four CMIP5 ESMs also show high increasing trends of air temperature but an increasing trend in rainfall. The latter is in contrast with the regional models used in this study. It should be noted again that only four out of more than 20 CMIP5 global models have been selected for this analysis based on one single downscalling and bias correction method. However, the opposing trends projected by the different models testify that climate change signals are rather uncertain in the Upper Niger basin and more generally in West-Africa.

(e) Upstream river management options

Scenarios are used in this case study to assess the combined impacts of upstream land and water management and climate change on the hydrology of the rivers Niger and Bani which determine the flooding patterns in the Inner Niger Delta (IND). People's livelihoods, ecological conditions, and ecosystem services in the IND do strongly depend on inflows of the rivers Niger and Bani rather than on rainfall in the region. Consequently, the human-ecological system of the IND is vulnerable to (upstream) changes of the flow regime. Therefore, different water management scenarios were developed and their impacts simulated with the eco-hydrological model SWIM. The scenarios comprise assumptions/targets derived from national development plans regarding the extension of irrigated areas and the construction of dams.

- **Dams**

In this scenario application we consider up to three reservoirs: Sélingué, Fomi, and Talo. We do not have enough information to parameterise the planned Dam in Djenné. The Sélingué dam is always operational in the model but the dams Fomi and Talo (not operational in reference period) are considered as scenarios.

- **Irrigation schemes**

Current and future Irrigation water uptake and efficiency were setup in line with the development plan of the Niger Basin Authority and the future dams in line with engineering technical report. The 7 main irrigation scheme plans were integrated in the SWIM catchment setup with three different irrigation efficiency applications for the Office du Niger. Water uptake was restricted to minimal flows (40m³/s at Markala and 10m³/s at Fomi, Sélingué, and Djenné).

Irrigation Scheme in ha	Rice	Rice CS	Gardening	Sugar Cane	Irrigation Efficiency m³/ha/y	Provision in l/ha/s
Sélingué	1600				31000	1.5
Baguinéda	3000	400			71500	2.2
Markala (ON)	77000	7700	15400	5000	30000 [SC:71200]	2.7 [SC:3.4]
Sélingué planned	3200				31000	1.5
Djenné planned	68000				13276	2.4
Talo planned	20000				13276	2.4
Fomi planned	3000			10000	11500	1
Markala ON extension 1)	220000	22000	44000	30000	13500 [SC:71200]	1.2 [SC:3.4]
Markala ON extension 2)	220000	22000	44000	30000	20000 [SC:71200]	1.8 [SC:3.4]
Markala ON extension 3)	600000	60000	120000	30000	24000 [SC:71200]	2.2 [SC:3.4]

Table 5: Summary of Irrigation scheme characteristics (crop type, irrigation efficiency, extensive area)

The irrigation water demand was then applied but the satisfaction in all months or in all years by water availability was not yet fully examined. The application of future projections of water demand is subject to high uncertainty as there are still a lot of uncertainties with regard to different assumptions in water uptake requirements according to different crop season as well as the infrastructure and channel capacities and related losses and the estimated irrigation efficiency applied to future extension of irrigation schemes.

- **Irrigation schemes**

The **scenario matrix** was defined with local stakeholder representatives from the IND region combining irrigation schemes, dams and climate change projections as followed:

	Climate		Reservoirs			Irrigation				
Name	RCP 2.6	RCP 8.5	Sélingué	Fomi	Talo	Markala	Djenné	Sélingué	Talo	Fomi
Scenario A	-	-	x	-	-	1)	-	-	-	-
Scenario B	x	x	x	-	-	1)	-	-	-	-
Scenario C	-	-	x	x	x	1)				
Scenario D	-	-	x	-	-	2)	x	x	x	x
Scenario D1	-	-	x	-	-	3)	x	x	x	x
Scenario E	x	x	x	x	x	2)	x	x	x	x
Scenario F	-	-	x	x	x	2)	x	x	x	x
Scenario IRR_E	-	-	x	-	-	4)	x	x	x	x

Table 6: Scenario matrix

Scenario A represents the *business as usual* (BAU) scenario for the period 1961-1990. It includes the Sélingué dam and the current water uptake at Markala. This scenario is always marked in grey colour in the boxplots of the following figures from this section..

Scenario B considers the two climate scenarios RCP 2.6 and 8.5 under *BAU* management conditions.

Scenario C includes following dams: Sélingué, Fomi, and Talo and the current water uptake at Markala. The simulations are based on climate conditions of the period 1961- 1990. Hence, this scenario is used to investigate the impacts of the planned Fomi dam in Guinea and the already built dam at Talo.

Scenario D is used to study the impact of an extension of irrigated area at Markala of 250,000 ha. On 220,000 ha we assume rice production and on 30,000 ha sugar cane. In contrast to irrigated rice, sugar cane requires water in all months of the year. An important assumption in this scenario is that the water use efficiency improves significantly from currently 33,000m3ha-1 and year to 13,500m3ha-1 and year. This information has been taken from PADD (Etudes Sur L'élaboration Du Plan d'Action de Développement Durable Du Bassin Du Niger). This assumption implies that although the extension is almost three times larger than the current area, the amount of water required is not so much higher. Therefore, the results do not look as dramatic as they might if we would assume current water use efficiency. The difference between scenario D and D1 are the different assumptions of water use efficiencies. Where an efficiency of 13,500m3ha-1 is assumed in scenario D, the efficiency in D1 is with 19,855m3ha-1 lower than in scenario D but still much higher than the current water use efficiency.

Scenario E includes the three upstream dams (Sélingué, Fomi, and Talo) and the extension of irrigated area by 250,000 ha. The assumed water use efficiency is with 13,500m3ha-1 very high (efficient).

The management conditions of **Scenario F** are similar to scenario E.

Scenario IRR_E is used to show the impact of extremely expanding irrigated areas to 600,000 ha as planned by Office du Niger. The water use efficiency was set to 24,000m3ha-1.

(f) Outcomes from scenario matrix application

Upstream land and water management as well as the variability of climate have significant impacts on discharges of the Rivers Niger and Bani. Large dams change the natural flow regime downstream and increase evaporation from the lake surface area. Additional losses by evaporation from Sélingué dam for instance, increase from 7% of storage volume to over 9% or from 2190 mm/a to 2320 mm/a, respectively (Scenario E: GFDL, RCP 8.5 for the periods 1970-1999 and 2070-2099).

Water abstraction from reservoirs and the diversion of river water to irrigated areas reduce river discharges. These changes of flow regime and the reduced total volume have impacts on the flooding patterns of the IND. These impacts are illustrated in this section and are thus the basis for the analysis of impacts on livelihoods.

The Figures Figure 45Figure 46 show the impact of climate change scenarios on inflows into the IND as the sum of flows of the Rivers Niger and Bani. Average peak discharges in the reference period under RCP 2.6 are 5893m³/s. Due to increasing rainfall during the months August and September; simulated discharge peaks are higher for the last two scenario periods (6600m³/s and 6612m³/s). Under climate conditions of scenario RCP 8.5, discharge peaks in 2011-2040 are higher (6485m³/s) than in the reference period but lower than in scenario RCP 2.6. As a result of decreasing rainfall from June to August and extremely increasing air temperature, peak discharges are with 5297m³/s lower than in the reference period.

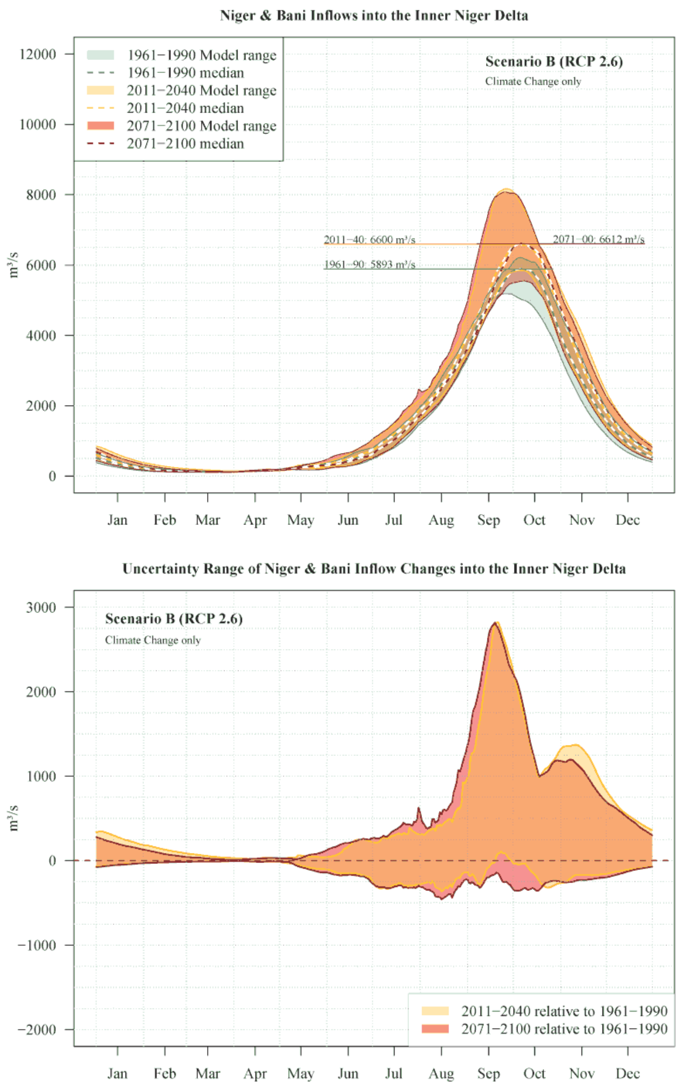


Figure 45 Scenario B: Impact of climate change on Niger & Bani dis:charge (RCP 2.6)

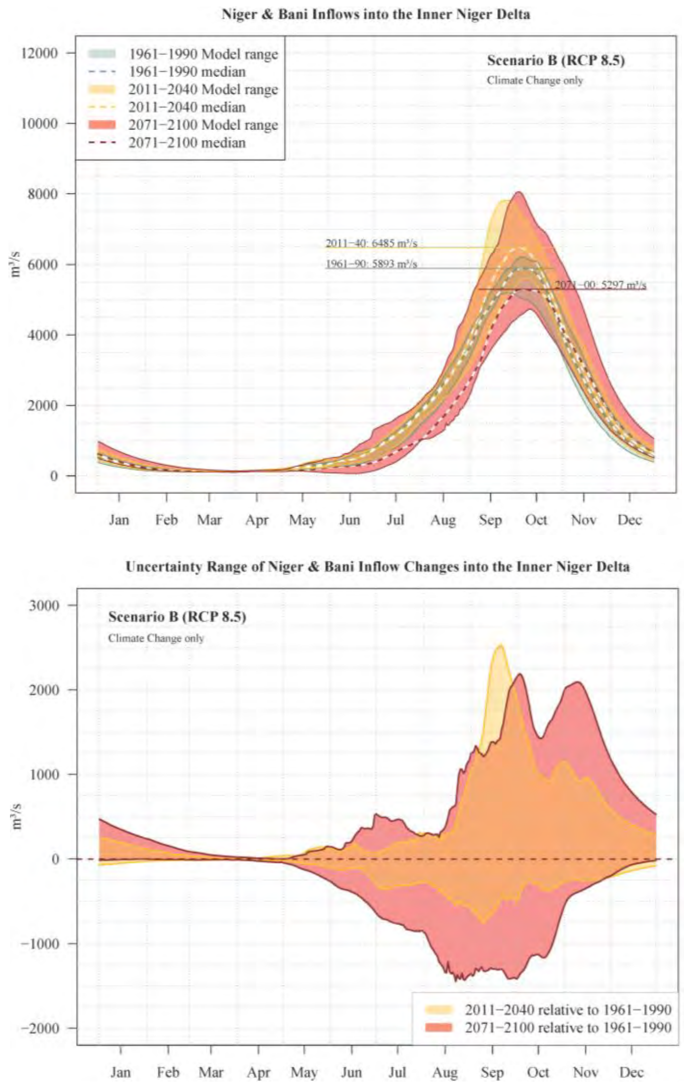
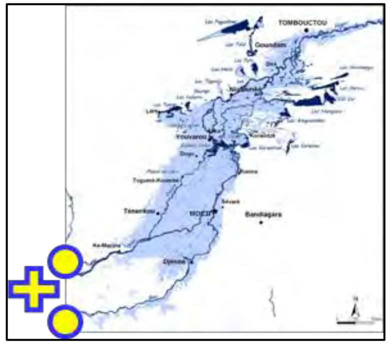


Figure 46: Scenario B: Impact of climate change on maximum flooded surface area (RCP 8.5)



The impacts of climate scenarios on the flooded surface area in the IND are shown in the two next figures. The boxplots represent the distribution of maximal flooded surface area per annum of the respective periods. The grey boxplot (BAU - *business as usual*) shows the range and distribution of simulated annual maximal flooded surface area during the period 1961-1990 using WATCH forcing data (also considered as Scenario A). The WFD were used to downscale and bias-correct the ESMs. The red line in the figures indicates the minimal and the blue line the maximal flooded surface area during the reference period. The dotted black line represents the median flooded surface area in the reference period. The second boxplot (lightblue) in each plot represents the reference period using the respective ESM climate as driver for the SWIM model. Comparing the grey and the lightblue boxplots shows the performance of the model to represent the past “observations”. The boxplots representing future periods are white. The white boxplots should be compared to the lightblue in order to evaluate the change of flooded surface area.

The blue boxplots show the range of flooded surface area for each model in the reference period. In RCP 2.6, the simulations driven by the ESMs HadGEM2 and NorESM1 indicate a general trend towards larger inundated areas in the future periods. However, the simulation driven by the ESM GFDL does not show a significant trend but a slightly decreasing trend the with ESM IPSL (RCP2.6). The impacts of a changing climate are more pronounced in the RCP 8.5 scenario as shown in RCP8.5. A rather strong decline of the flooded surface area is simulated with climate inputs from the IPSL model. The simulations driven by the HadGEM2 model show a different picture than under scenario RCP 2.6. An increase is projected for the period 2011-2040 but a rather strong decrease for the end of the 21st century. The simulations driven by GFDL and NorESM1 do not show significant trends.

Figure 50 shows the impacts of land and water management scenarios on the flooded surface area in the IND. Climate change is not considered in this figure. All scenarios were simulated using the climate of the period 1961-1990 which covers a wide range from extremely dry to wet years. According to Figure 50, upstream dams do not have an impact on the median value of simulated flooded surface area but on the distribution of the values between the upper and lower quartiles (the box itself). Both values experience a downward shift, meaning that there is a negative impact on the flooded surface area in dry as well as in wet years. The numbers below the boxplots indicate the change of the mean flooded surface area. Hence, the impact of three upstream dams leads to a reduction of 3.2% of the average maximal flooded surface area. The boxplot of scenario D in Figure 3.6 shows that this irrigation scenario does not have a large impact on the flooded surface area during wet years (upper quartile of the box) but shows a rather strong impact during drier years (lower quartile of the box). The average flooded surface area is reduced by 4.7% in scenario D with a water use efficiency of 13,500m3ha-1 and 6.3% in scenario D1 with a lower water use efficiency of 19,855m3ha-1. The rather low impacts can be explained by the high water use efficiencies applied in these scenarios. Figure 49 shows the impact of three dams upstream (Sélingué, Fomi, and Talo) and the extension of irrigated area by 250,000 ha on discharge at gauge Dire (IND outlet). It shows the discharge range simulated by SWIM using the four climate models in the reference period represented by the green and red bands. Hence, climate change is not considered in this plot and it thus represents the conditions comparable to Scenario F in Figure 50. The impact of upstream water management on discharge at the IND outlet can be considered as strong. Peak discharges in November are reduced by more than 250m3/s (-15%) and river flow is reduced in all months except in May and June. An extension of irrigated area by Office du Niger to 600,000 ha (scenario IRR_E) would have a significant impact. The mean flooded surface area is reduced by 17% in this case.

Figure 47: Scenario B: Impact of climate change on maximum flooded surface area (RCP 2.6)

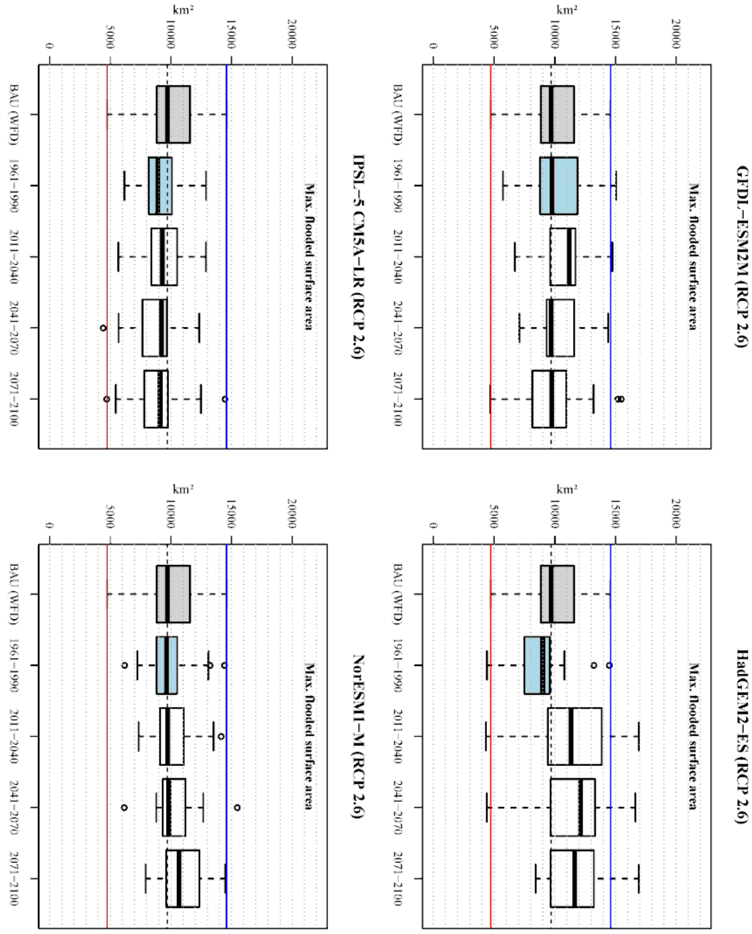
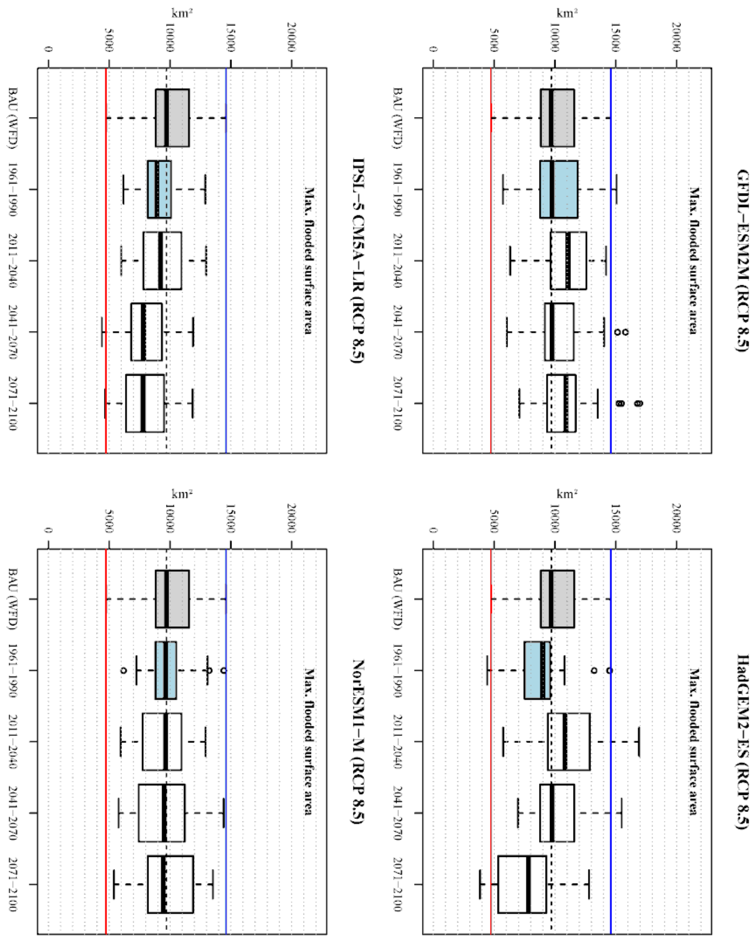
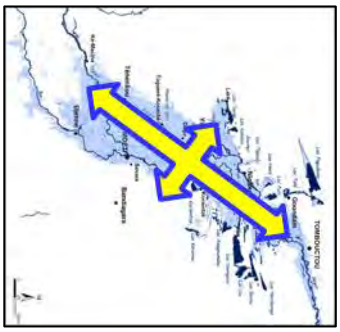


Figure 48: Scenario B: Impact of climate change on maximum flooded surface area (RCP 8.5)





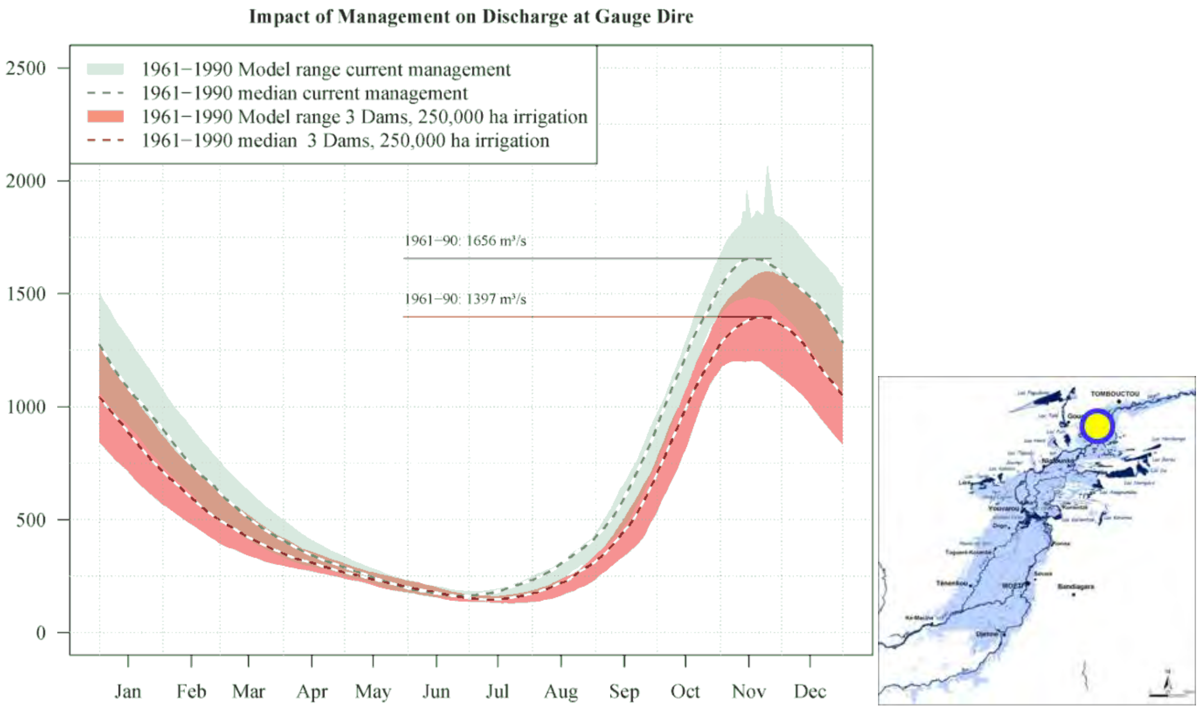


Figure 49: Scenario E: Impact of Dams and Irrigation on Discharge at Gauge Dire (1961-1990)

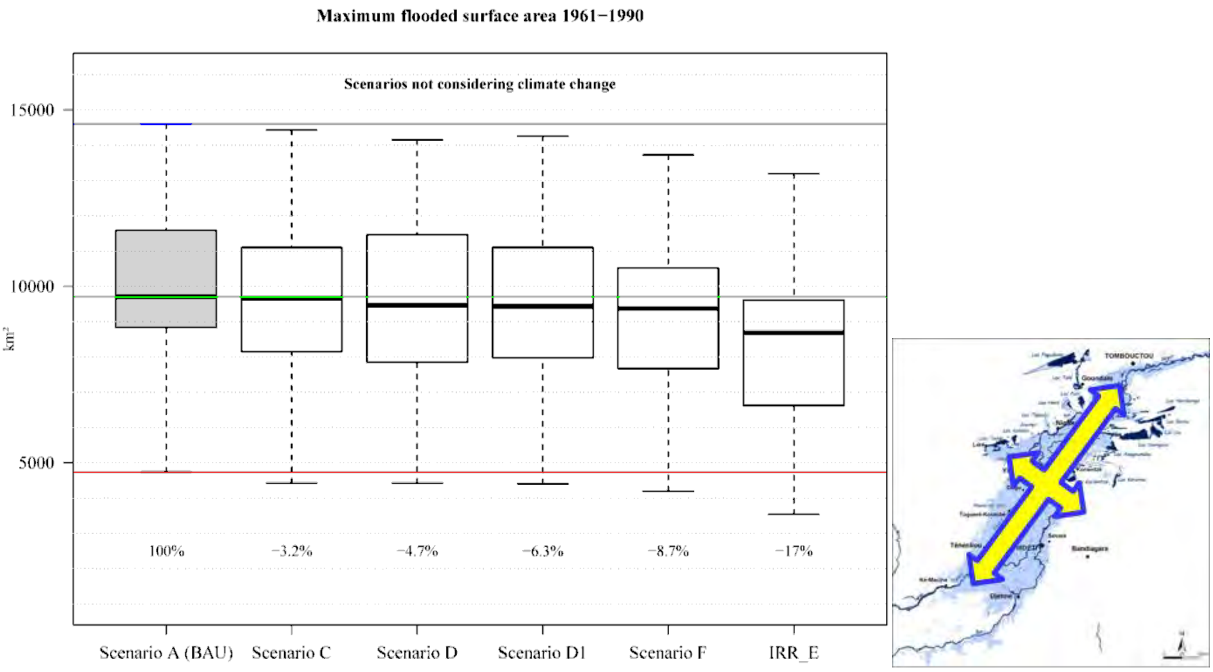


Figure 50: Scenario A, C, D, D1, F, and IRR_E: Impact of management on maximum flooded surface area. Numbers below the boxplots indicate the change of mean flooded surface area relative to the BAU scenario.

(g) Summary

Climate Change

According to the analysis of four ESMs, the uncertainties regarding future climate change and variability are very high. Particularly with regard to the most important variable: rainfall. However, the models show agreement in temperature trends. Hence, all models show in all scenarios an increase of air temperature which has certainly implications for actual evapotranspiration. The period 2011-2040 is expected to be 1.2 to 1.4℃ warmer than the reference period (not pre-industrial era). The temperature trends of the two climate scenarios differ significantly in the periods 2041-2070 and 2071-2100,

Liersch et al., 2005 used a statistical regional climate model which projected a very dry future for the Upper Niger Basin. If we look at the model range in this document these assumptions can be considered as very pessimistic. On the other hand, we should emphasize that only four out of more than 20 available global models were used here. There are indeed several models that project a drier future for the Upper Niger Basin, but changes become sometimes only obvious in the second half of this century. According to the study at hand, the median of the four ESMs indicates an increase of average annual rainfall in the next three decades by 8% relative to the reference period. However, rainfall projections do also show that there might be years or periods as dry as in the 1980s. Moreover, it shows, particularly under RCP 8.5, a drying trend at the beginning of the rainy season.

Dams

Dams have a moderately negative impact on flooded surface area. The construction of new dams and reservoirs in the Upper Niger Basin will negatively affect the flooding regime of the Inner Niger Delta. Dams will certainly have an impact during both dry and wet years. Average reduction of maximal annual flooded surface area manifests in a decrease of 3.2% in this study if the two dams (Fomi and Talo) are implemented.

It should also be noted that there might be a positive trade-off between the construction of new dams and irrigation in ON during the dry season (to the expense of flooded surface area in the IND). Management of upstream reservoirs is very likely to increase discharges during the dry season. This surplus might be beneficial for irrigation purposes in areas managed by ON.

Irrigation

Depending on the extent of irrigated area and water use efficiency, the impact on flooded surface area can be very significant. The implementation of moderately increasing water demands for irrigation in the model (ON at Markala 250,000 ha, Fomi, Sélingué, and Djenné) have negative impacts on the flooded surface area during both dry and wet years. The impact manifests in a reduction of 4.7% of the mean of flooded surface area, see Scenario D in Figure 50. The underlying assumption was a very high improvement of water use efficiency as stated in PADD. If water use efficiency does increase only slightly, the impact would lead to a reduction of mean flooded surface area by 6.3%. An extension of irrigated area in ON to 600,000 ha would have a rather large impact. The mean flooded surface area is reduced by 17% in this case. However, a detailed investigation of impacts during dry and wet years, for instance, is still required. This study is just a quick attempt to assess likely impacts and there is a need to discuss the irrigation scenario assumptions regarding water demand, water use efficiency, channel capacities, crops etc.

3.3 SKILL ASSESSMENT AND IMPROVEMENT OF AN OPERATIONNAL COMMUNITY BASED FLOOD PEAK PREDICTION TOOL: OPIDIN

3.3.1 Introduction

In the Inner Niger Delta, communities managed natural resources with complex traditional customs and societal organizations to adapt and harmonize farming, fisheries, and livestock activities to the high seasonal and inter-annual variation of rainfall and flood dynamics.

Over the last decades, a persistent drought period, coinciding with upstream steer investments in hydraulic infrastructures to support hydropower generation and irrigation farming, alters the flood propagation regime in the delta which, in turn, compromised the livelihoods of about 1.5 Million riverines as well as the conservation of the floodplain habitat, the second biggest Ramsar site in Africa, hosting from 3 to 4 Million migratory waterbirds.

With this new paradigm, the use of tailored forecast instruments can support communities to select appropriate livelihood options and timing for socio-economic rural planning and events. It can concretely help to mitigate suboptimal yields, sheer mis-investments but also the emergence of conflicts in the context of collective overexploitation or mismanagement of natural resources. Based on statistical relationship from long time series of water levels, the flood prediction tool of the Inner Niger Delta (OPIDIN) is designed to evaluate the flood peak and timing and to facilitate the implementation and the dissemination of forecast information at community based level (Zwarts, 2009a, 2009b). OPIDIN tool functions and skills are then assessed when the potential for technical improvement to increase its forecasting capacity are also foreseen. However, more importantly reported are the processes to structure an operational and representative stakeholder platform which succeeds to disseminate early warning information and secure livelihoods all the way to village levels. The local consultative approach initiated with OPIDIN allowed identifying community and economic sector without significant options to adapt to drought hazard for which cooperation projects need to be further developed to find sustainable alternatives

(a) Monitoring of the IND´s Flood dynamics

The seasonal flood dynamics in the Inner Niger Delta have been measured daily by DNH (Direction Nationale de l´Hydraulique du Mali) at several hydrometric stations over many decades, producing a time series of great value. These stations are (see map in Figure 51):

- Douna, Bénény-Kegny and Sofara, along the Bani river,
- Ké-Macina in the Niger river at the entrance of the Inner Niger Delta,
- Mopti, Akka, Niafounké, Diré and Goundam in the Inner Niger Delta itself.

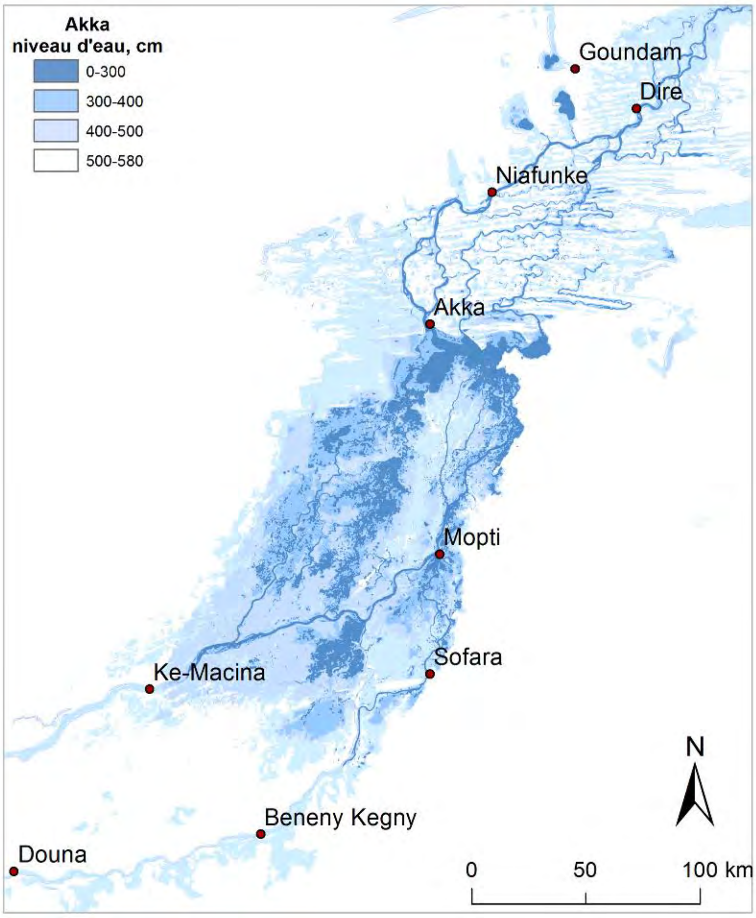
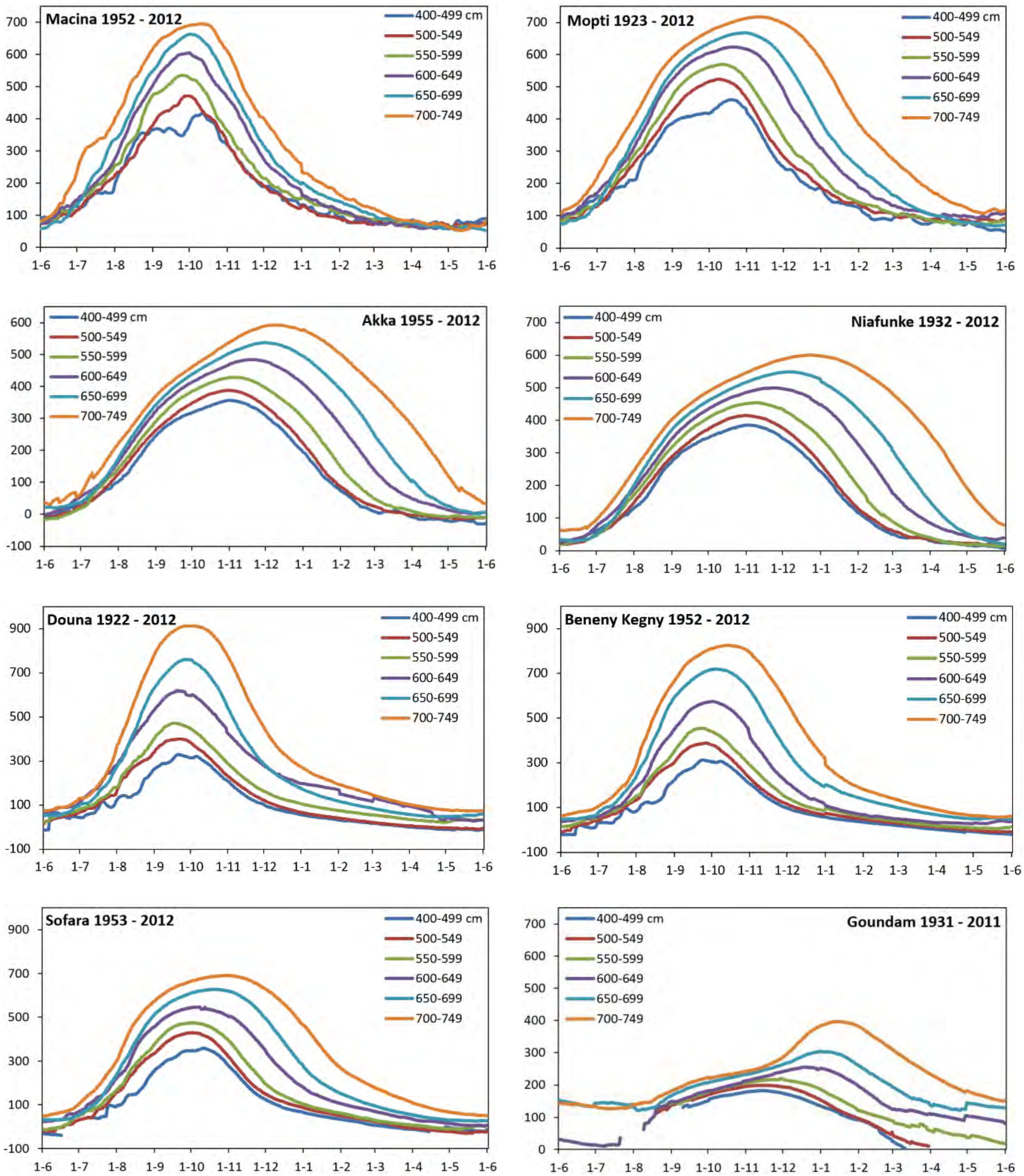


Figure 51: Nine hydrometric stations used in OPIDIN. The four colours blue show the flood extent in the Inner Niger Delta at different flood levels in Akka

Figure 52 clearly shows that the seasonal flooding curves are different in years with a high and low flood. To investigate the variation in the flood curve as a function of the flood height, all daily measurements were subdivided into six categories according to the height of the peak flood in Mopti (400-499cm; 500-549cm; 550-599cm; 600-649cm; 650-699cm; 700-749cm). In average years, flood height reaches 6.1 metres on the 21th of October at Mopti and 4.8 metres at the 16th of November at Akka, slowly engulfing an area of 400 by 100 km^2. During the flooding and the de-flooding the water level rises and declines on average 3-5 cm per day.



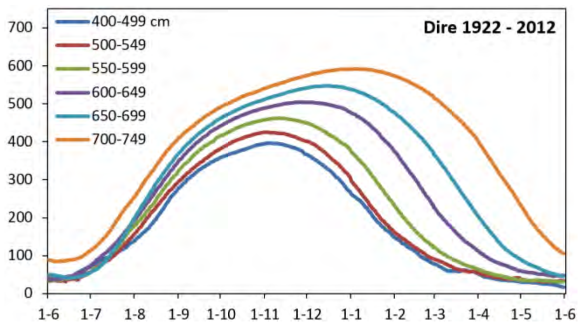


Figure 52: The average flood curves (cm) during the year from June till June next year in 9 stations in the Inner Niger Delta and Bani using all DNH's time series. The flood curves are given for six categories of peak flood levels in Mopti: 400-499cm; 500-549cm; 550-599cm; 600-649cm; 650-699cm; 700-749cm Source: Zwarts, 2013

The flood peak is then in average delayed of 26 days and decreases of 1.3 m. between Mopti and Akka due to the propagation and water losses by infiltration and evapotranspiration processes. At Mopti, in years of low river flow, the water reaches a height of about 3.5 m, peaking in late October. At high river flows, although the water level rises at the same daily rate, it does so over a longer period, peaking at 6 to 7 metres by late December.

(b) How people's livelihoods depend on flood dynamics

The economy and the ecosystem of the IND are strongly driven by these flood dynamics. In other words, the IND is a flood-dependent ecosystem and economy. As an example, rice production, especially the floating rice variety, the staple food in the IND fails when water levels are too shallow. Given recent changes in the water regime (due to upstream dams and diversions), climate change and the natural occurring variability, farmers may lack the knowledge to choose the best suited areas for their rice production.

Fish catches are determined by the area flooded which vary with flooding levels. Catches vary between 50,000 to 100,000 tons for minor and major flood years, respectively (Zwarts et al. 2005). The uncertainty of this fish production places the livelihoods of the 300,000 fishermen in this area under continuous pressure. Also, cattle-grazing is planned since historic times in conformity to cultivated areas and flood levels. Herders and their cattle need to cross the river during to access the de-flooded fields with Bourgou (local grass variety used as fodder). There are 32 frequently-used crossings. The date at which cattle are allowed to cross the river differs for the various official crossing-points. Limited flooding reduces the Bourgou growth hereby affecting livestock productivity.

(c) OPIDIN flood prediction tool utilities and development phase

OPIDIN (***O***util de ***P***rédiction des ***I***nondations dans la ***D***elta ***I***ntérieur du ***N***iger) utilizes the statistical relationships between DNH's recorded water level time series at the various hydrometric stations to predict the flood dynamics in the Inner Niger Delta. OPIDIN predicts the maximum flood level and the date at which the flood peak is reached, but it may also be used to predict the water level during different stages of the flooding curve, e.g. the date at which the water level has declined to a certain level. As such, it functions as an early warning system for the people living in the Inner Niger Delta who livelihoods are governed by the flood dynamics.

The flood prediction function of OPIDIN allows various stakeholders in the IND to optimize the planning of their livelihood activities and to make no-regret investments. Fishers can select fishing sites, modify their practices, and optimize preparatory activities (investments to purchase appropriate fishing gears, risk free investment). Herders can plan to use different regional transhumance routes (temporary migration to other parts of the country) and trails in the IND to adapt to the timing of grazing in the bourgou pastures. Timing and rural planning of rice production sites and agricultural practices are subject flood levels. Flood level forecast might encourage early starting of rice farming in lowland areas or to use dry resistant type of rice (field preparation, removal of animals). Timing of socio-cultural activities and festivities, often determined by the flooding pattern, could then also be better anticipated. Last but not least, people adopting as adaptation strategies temporary migration (leaving the Inner Niger Delta in years with a poor flood to work elsewhere in Mali or even abroad), may plan to leave their village when they know already in August that the flood will be low.

An initial version of OPIDIN was developed in 2009 within a study carried out by Royal Haskoning (lead), Altenburg & Wymenga Ecological Consultants (A&W) and Wetland International and funded by the Dutch donor Partners for Water. This first version of OPIDIN was described by Zwarts (2009a). In the framework of the Wetland & Livelihoods Project GIRE (Gestion integrée de resources naturelles), A&W and Wetlands International (Mali office) further improved OPIDIN (Zwarts, 2009b). Currently (2013), the improvement of the OPIDIN tool and especially the embedding of the tool in operational water resources management of DNH and the dissemination of early warning information to various stakeholders is carried out by a consortium of A&W, Wetlands International, Deltares and some consultancies and is funded by the Dutch Embassy in Mali.

In this context, the DEWFORA project aims to support this continuous improvement and valuation of the OPIDIN tool. In collaboration with AFROMAISON FP7 project, workshops were organized with key regional and local stakeholders of the OPIDIN stakeholder platform (Wetlands International, 2012). In these workshops various stakeholders were consulted and it was clearly expressed that OPIDIN is a preferred tool for drought early warning. It was expressed that the relatively easy operation of the tool is an added value compared to tools that need lots of technical expertise and data input. Basically, only continued measuring of water levels in the hydrometric stations are needed to sustain OPIDIN' predictive function.

Stakeholders that attended these workshops were: DNH, National Niger Basin Authority (ABFN), Mali , Regional Direction of fishery (DRP), GDRN5, Regional Assembly of Mopti (ARM), farmers, fishermen and pastoralists representatives and mayors of various IND villages, Regional Direction of Agriculture (DRA) Mopti, FODESA, Sahel Consult, Sustainable Development Program IND (PDD-DIN), CARE, DREF / Mopti, Regional Direction of Hydrology (DRH), DRPS IAP, Office Riz Mopti, Office du Niger, Water user committee (CNU) of Bamako. Within DEWFORA, also a skill assessment of the initial version of OPIDIN tool (WP4-D4.8) was carried out.

(d) OPIDIN improvement: inclusion of the Sélingué Dam

As the regression equations used in OPIDIN are based on the hydrometric data from 1956 onwards, the implicit assumption of the model is the flooding and de-flooding curves vary with river discharge only. However, the flood curve in the Inner Niger Delta is altered significantly since 1982 with the construction of the Sélingué dam. This dam especially stores water during the wet months significantly reducing the river discharge into the IND in those months. Water from the reservoir is released to the Office du Niger and released to produce hydropower.

The prediction of peak flood level in the current situation (thus with Sélingué) using regression equations calculated over all historical data would then be biased. This problem could be solved by only using measurements after the construction of the Sélingué dam. Instead, data before and after 1982 are separated and a multiple regression equations are calculated with a common slope but a different intercept to take into account the difference before and after the construction of Sélingué (Zwarts, 2013). This is illustrated in Figure 53 for the prediction of the peak flood in Mopti based on the water level measurement in Mopti at the 1st of August. The red line in the graph is used in OPIDIN to predict the peak flood level.

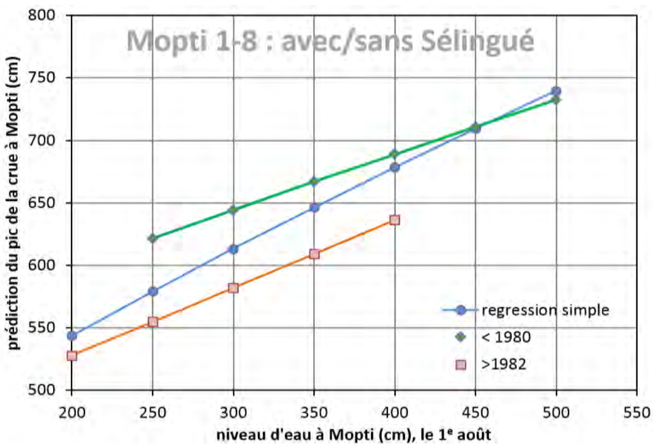


Figure 53: Data from 1st of August is used to calculate a regression equation for all data (blue line; "regression simple") and a multiple regression equation where the data were split up before (green line) and after (red line) the construction of Sélingué. Note that the slopes of both regressions are equal and that only the intercept differs. Source: Zwarts 2013

(e) OPIDIN functions and statistical regression improvement

The predictive capacity of OPIDIN is based on statistical relationships of the measured water level data in the various hydrometric stations upstream from and in the IND. Based on these relationships, regression equations are develop that allow to:

- relate the measured water level in the period July-September at a hydrometric station to predict the timing and level of peak flooding at that station.
- relate the peak water level at a hydrometric station to predict the timing of a possible river crossing at station (certain threshold de-flooding is reached)
- relate the peak water level at a hydrometric station to predict the peak level at a downstream station
- relate the peak water level at a hydrometric station to predict the timing of de-flooding at a downstream station
- relate the measured water level in the period July-September at a hydrometric station to predict the timing and level of peak flooding and the timing of de-flooding at a downstream station

In the earlier version of OPIDIN linear regression techniques were used. Zwarts (2013) showed that the above mentioned inter-station relationships to predict peak levels are merely linear in August. However, later in the season they become curvilinear. Hence in the improved version of OPIDIN, second degree polynomials are used to relate water level in August - October to the peak flood levels.

3.3.2 Skill assessment of OPIDIN

In this section some skill analyses are presented carried out in the Dewfora and the OPIDIN improvement project funded by the Dutch Embassy in Mali.

Table 7 shows the statistical correlations (curvi-linear) between the peak levels of upstream hydrometric station to the peak levels in Mopti and between the peak levels in Mopti and the peak levels in downstream stations. The table furthermore shows statistical correlations between peak levels at hydrometric stations and its timings. Generally speaking the statistical relationships between peak levels at various hydrometric stations have better correlations than between peak levels and the timing of that peak level.

Table 7: the explained variances (R2) for curvi-linear relationships between peak levels of upstream hydrometric station to peak levels in Mopti and between peak levels in Mopti and peak levels in downstream stations (left-column) and peak level timings (right column) Source: Zwarts 2013

Hydrometric station (upstream to downstream	Statistical correlation (R^2, curvi-linear) of flooding peak levels between upstream and downstream hydrometric stations	Statistical correlation (R^2, curvi-linear) of timing a of flooding peak and the flood peak level at a hydrometric station
Douna	0.8811	0.1633
Ké-Macina	0.9254	0.0099
Mopti	1	0.6485
Akka	0.9744	0.8042
Niafounké	0.9429	0.8314
Diré	0.9601	0.8752
Goundam	0.8461	0.6445

Based on the collected water level measurement regression equations are developed to relate water levels measured at various dates (from 1st of August to 16th of October) in Mopti to the peak flood levels and timings in Mopti, Akka and Dire. The explained variances (R2) of these regression equations are given in

Table 8.

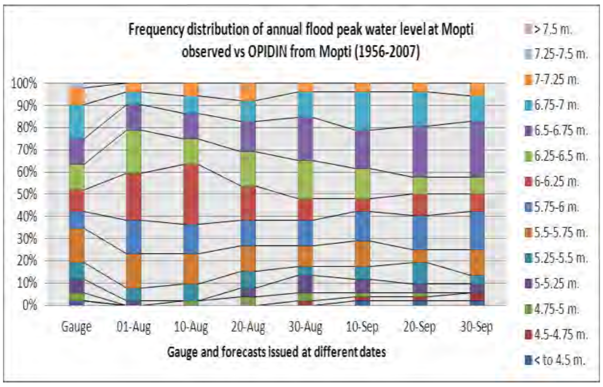
Table 8: Statistical correlations (R2) between water level measurements at Mopti at various dates and peak levels and its timings in Mopti, Akka and Diré. Source: Zwarts 2013

Date	Correlation of peak flooding level (R^2)			Correlation of peak flooding timing (R^2)		
	For Mopti based measurement in Mopti at dates	For Akka based measurement in Mopti at dates	For Dire based measurement in Mopti at dates	For Mopti based measurement in Mopti at dates	For Akka based measurement in Mopti at dates	For Dire based measurement in Mopti at dates
1-8	0.63	0.63	0.71	0.34	0.43	0.51
6-8	0.65	0.66	0.73	0.37	0.46	0.53
11-8	0.67	0.66	0.73	0.35	0.44	0.51
16-8	0.73	0.71	0.77	0.36	0.46	0.54
21-8	0.79	0.77	0.81	0.41	0.51	0.58
26-8	0.82	0.81	0.84	0.44	0.55	0.61
1-9	0.85	0.83	0.86	0.44	0.55	0.63
6-9	0.88	0.86	0.88	0.46	0.56	0.65
11-9	0.91	0.88	0.89	0.47	0.57	0.67
16-9	0.93	0.90	0.90	0.47	0.58	0.68
21-9	0.95	0.91	0.91	0.48	0.59	0.69
26-9	0.96	0.91	0.91	0.48	0.60	0.69
1-10	0.97	0.92	0.92	0.50	0.61	0.71
6-10	0.97	0.93	0.93	0.51	0.64	0.72
11-10	0.98	0.93	0.93	0.53	0.66	0.74
16-10	0.98	0.95	0.94	0.55	0.70	0.76

(a) Retroactive forecast skill based on Frequency distribution

Figure 54 compares frequency distributions, expressed in % of annual flood peak water level (left column) and of annual flood peak timing (right column) observed at Mopti in 1956-2007 with those predicted by OPIDIN (original version with linear regression). In each chart, the first (most left) bar represents the observed frequency distribution and the subsequent bars to the right show the evolution of predicted distributions with decreasing forecast lead time (from 1th of August to 30th of September). Each colour represents a specific interval of peak flood water level (left column) and peak flood timing (right column).

The observed frequency distributions are better distributed among all classes compared to the OPIDIN predictions. This skill assessment also shows that the frequency of the peak water level and timing in OPIDIN prediction tends to capture higher and lower classes whit decreasing lead time. However, the frequency distributions of really extreme low and high classes are generally underrepresented.



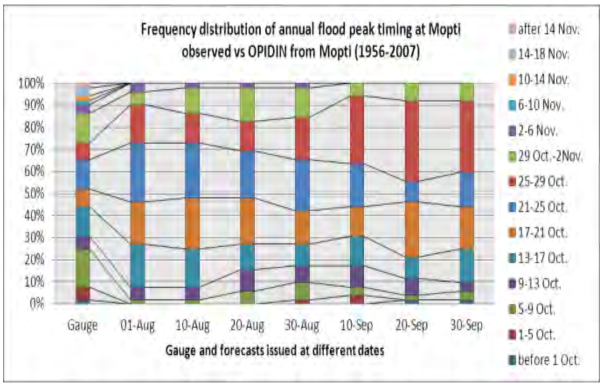


Figure 54: Observed and OPIDIN-predicted frequency distributions of peak flooding levels (left column) and timings (right column) in Mopti based on linear regression equations

(b) General retrospective forecast skill using quantitative deviation errors

Figure 5 compares the quantitative deviation errors frequencies expressed in % of the annual flood peak water level (left column) and of the annual flood peak timing (right column) between retrospective OPIDIN predictions against observed time series at Mopti (first row) and Akka (second and third rows) from 1956 to 2007. This is done at seven different water level monitoring dates (each bar in each chart representing a monitoring date. The OPIDIN predictions are based on Mopti time series for the first and third rows and on Akka for the second rows. Each colour represents a specific interval error expressed In meter for the peak flood water level (left column) and expressed in days and weeks for the peak flood timing (right column).

Figure 55 shows clearly that peak water level prediction (left column), OPIDIN increases largely its prediction skills with decreasing lead time. The peak water level prediction at Mopti demonstrates better skill than the predictions for Akka. The probability to get an error superior to 1 meter in the OPIDIN predictions gets really low when the monitoring date is later than 10th of September.

In the right column, OPIDIN's skill to deliver appropriate peak timing is presented. Results show a low probability to match the timing for plus or minus 2 days. Moreover, OPIDIN's skill only improves only limited when lead time decreases.

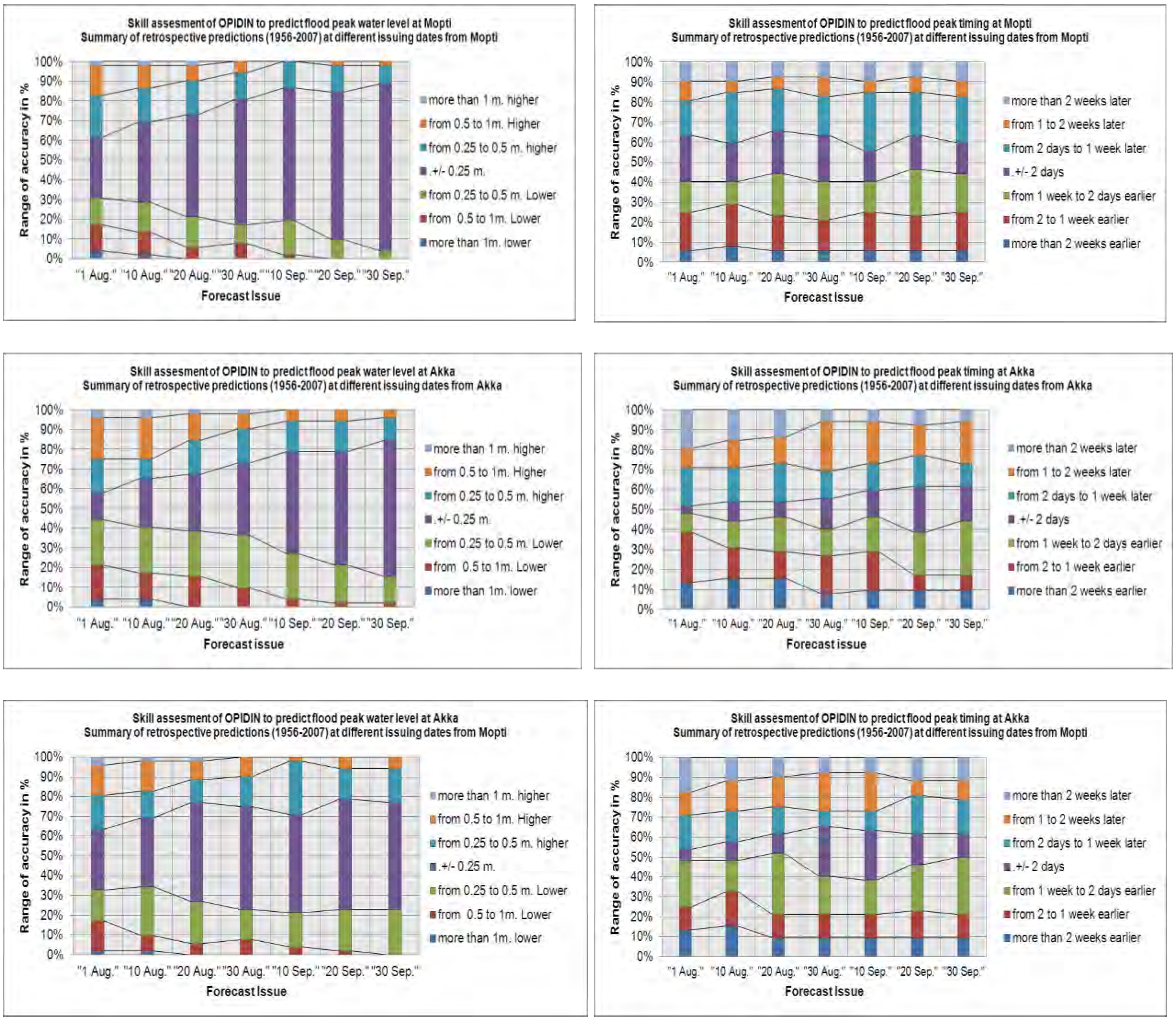


Figure 55: Forecast skill using quantitative deviation errors for peak levels (left column and peak timings (right column) for Mopti (1st row) and Akka (2nd and 3rd row)

(c) Extreme situation's retrospective forecast skill using quantitative deviation errors

In order to capture OPIDIN's skill to predict extremes (dry or wet episodes) Figure 56presents the quantitative deviation errors frequencies expressed in percentage between the retrospective OPIDIN predictions for Mopti (version with linear regression only) of the annual flood peak water level at seven different water level monitoring dates (each bar representing a monitoring date) against observed time series at Mopti.

The left column represents dry episodes while the right column represents wet episodes. The 1st row presents results applied to the 10 years of the time series with the lowest and highest annual discharge (first row), The 2nd row applied to the 10 years of the time series with the earliest and latest annual flood peak timing (second row) and the 3rd row applied to the 10 years of the time series with the lowest and highest annual flood peak water level.

When the charts are compared from row to row, results look relatively similar. The deviation error remains slightly higher when applying early and late flood peak timing. As early flood peak timing is highly correlated to low annual discharge and low peak water level, the results then remain similar because the 10 years selected were finally almost similar for the three methods. Same remark can be addressed for extreme wet periods. OPIDIN increases largely it prediction skill for dry and wet episodes when decreasing lead time. For dry episodes, the probability to get an error superior to 0.5 meter in the OPIDIN predictions gets low (<10%) when the issuing date is in September and using any of the three methods. However, the probability to get an error superior to 0.25 meter in the OPIDIN predictions in these extreme situations remains relatively high.

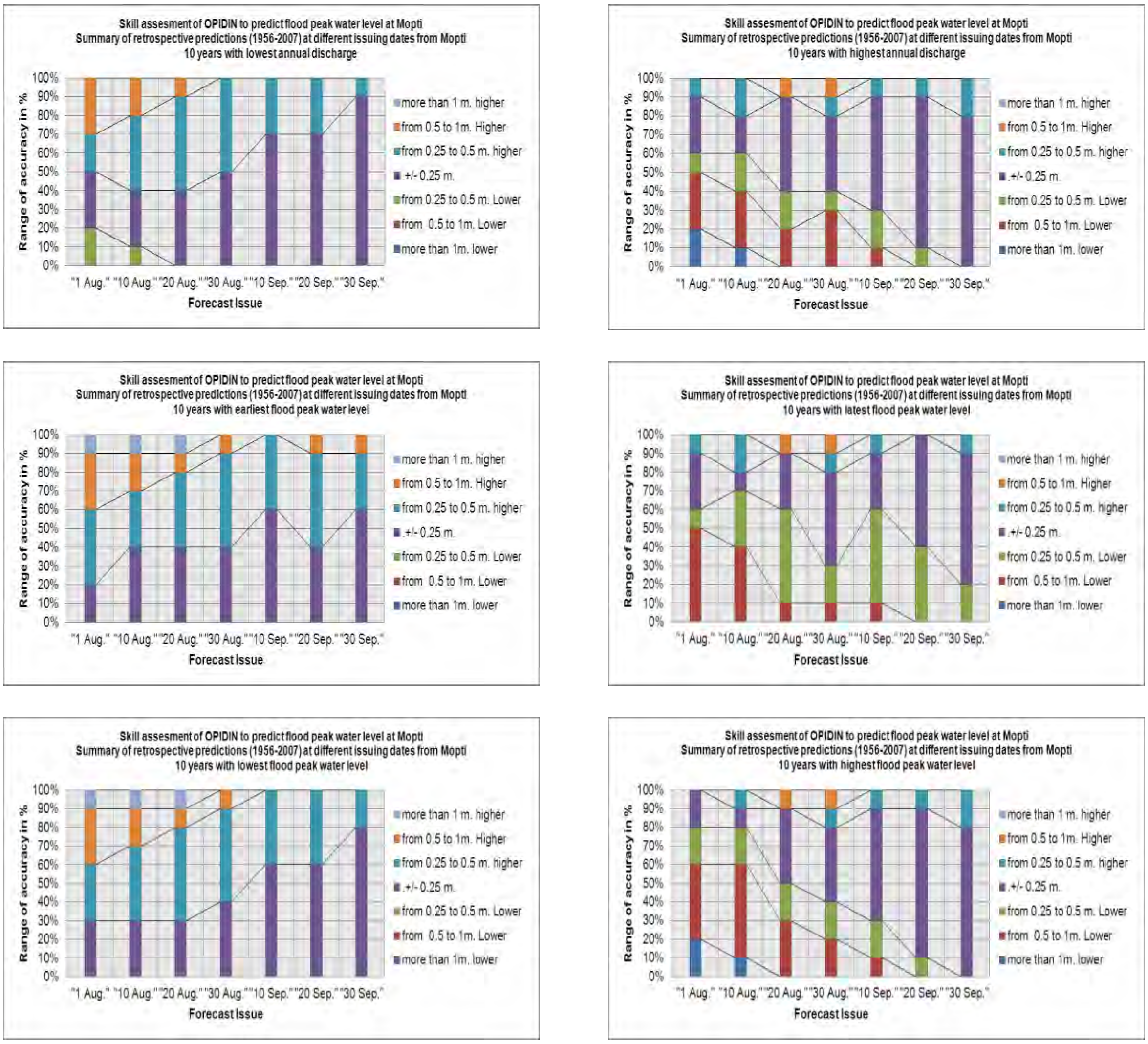


Figure 56: Forecast skill using quantitative deviation errors for peak levels at dry extremes (left column) and dry extremes (right column) for Mopti

(d) Confidence intervals peak level predictions of improved model

The developed regression equations relating water levels measured in Mopti at various dates (from 1st of August to 16th of October) to peak flood levels and timings in Mopti, Akka and Dire provide the possibility to accompany the predictions with confidence levels. In Figure 57, the 95% confidence levels for peak flood levels in Mopti, Akka and Diré based on Mopti-based water level measurements are given. Within 95% confidence, OPIDIN is able to predict the peak flood level with a range of 35-45cm in the beginning of August to a range of 10-20cm in mid-October.

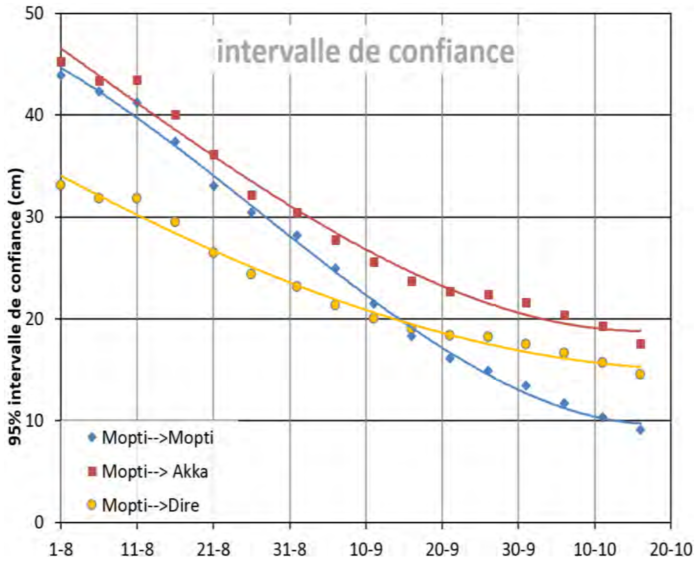


Figure 57: Confidence intervals of the 18 regression equations relating the water level at certain dates in Mopti to the flood peak in the same year in Mopti (blue symbols), in Akka (red symbols) and in Diré (yellow symbols) Source: Zwarts 2013

3.3.3 From forecasting to early warning system

The current improvement (Dutch Embassy funded project) of OPIDIN only partly entails increasing its predictive skill. It lies more importantly in adding value to the tool by converting the predictions in timely, practical and meaningful information for the people who rely on flood dynamics information to make no-regret operational livelihood decisions.

Hence a number of actions are undertaken to ensure the embedding of the OPIDIN tool in the relevant and responsible operational water resource management entities and to ensure the continued dissemination of OPIDIN early warning information. The activities currently undertaken are:

- The production and dissemination of an Inundation Atlas of the IND explaining how peak flood levels and flood extents may be derived from the actual water level in Mopti and Akka in August/September. The Atlas gives tables allowing the reader to extract the predicted flood level and flood extent from the water level measured in Akka and Mopti between 1 August and 15 October. The report also gives detailed maps showing the areas being flooded at different flood levels. The Atlas is produced and spread in hardcopy and softcopy (various carriers like DVDs) and is accessible via the newly develop website dedicated to OPIDIN (see next point)
- A website is developed dedicated to the OPIDIN tool (www.opindin.org both the English and French language (see Figure 58). The website contains all background information on the OPIDIN tool, the above-mentioned Inundation Atlas. The website contains predictions of the peak flood levels and peak flood timings in Mopti, Akka and Dire based on the most recent water level measurement in Mopti (including the 95% confidence interval values. Furthermore, the website provides predictions for the timing of de-flooding in Akka (100 and 200 cm de-flooding) based on the most reason measured water level in Mopti. The web-viewer provides maps with the flood extents at the predicted flood peak levels. Besides predictions, the website will provide weekly bulletins where the predicted values are translated in easy to understand flood dynamics information (see next point).
- A weekly early warning bulletin will be developed based on OPIDINS predictions. These bulletins contain easy to understand flood dynamics information. Surveys launched in various OPIDIN stakeholder workshops and among the population of the IND show that people have a collective memory regarding to the flood levels in the past. For instance, people in the IND know very well that there were high floods in 1994 and 1999 and a low flood in 1984 (Zwarts, 2010). This facilitates the transfer of OPIDIN's predictive values to relevant and historical information, e.g. "the flood level

this year will be low, - about as high as in 2002, 2004 and 2005". The bulletin is broadcasted via various radio stations and will also include meteorological forecasts.

- Additionally, people can apply for a paid text-message service or calling a dedicated phone number providing them with on the spot most recent information on flood levels and timings and including meteorological data.

As known, most of IND's livelihood activities are strongly dependent on flood levels, timings and flood extents. However, for the productivity of rice and bourgou pasture (cattle fodder) the pre-flooding, rainfall in the IND is essential as well. Rice germination and eventual crop yields strongly depend on the initial soil moisture content. Irrigation is only limitedly developed in the IND and hence the importance of the rainfall. One of the currently considered and foreseen improvements in the OPIDIN tool is to combine the flooding dynamics predictions with rainfall forecasts. This may be augmented with soil moisture content predictions making used of additional meteorological, soil and agro-technical information.

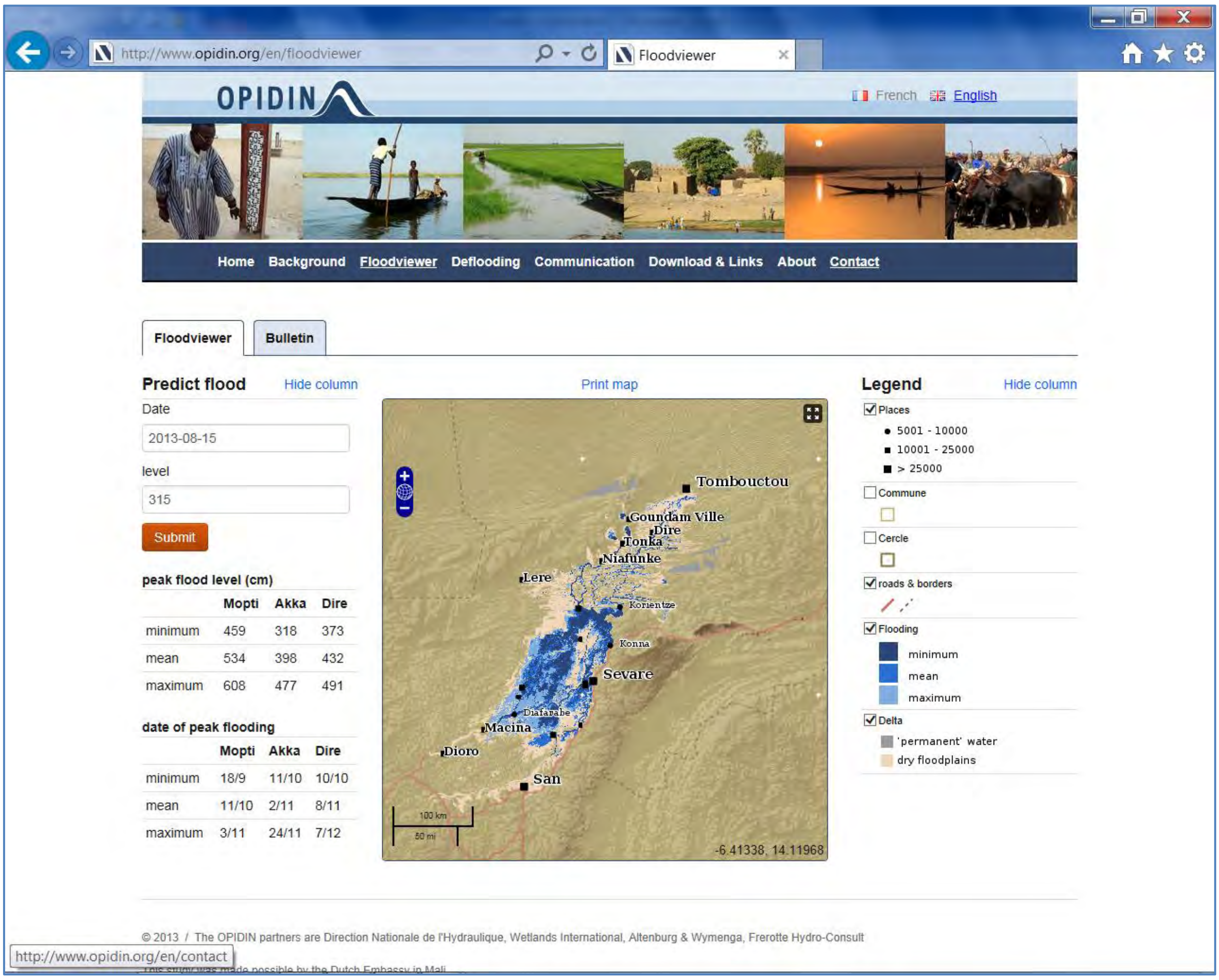


Figure 58: the OPIDIN web tool

4. REGIONAL DROUGHT VULNERABILITY AND ADAPTIVE CAPACITIES

4.1 INTEGRATED WATER RESSOURCES MANAGEMENT

4.1.1 Water-use, Stakeholder and stakeholder platform:

(a) Water use at the Niger River basin scale

The withdrawals of surface water in the catchment basin of Niger have been the subject of a recent study "Evaluation of withdrawals and water needs for the simulation model of the Niger Basin" (BRL and DHI, 2007b, PADD Phase2, NBA). In 2005, water abstraction in the Niger River Basin presented the following ratio: 84, 13 and 3% respectively for irrigated agriculture, supply of drinking water to the population and drinking water for livestock. Since then, the increase in water withdrawals come mainly agricultural sector. Also, this study identified the current withdrawals (2005) and future needs (the horizons 2015 and 2025), surface water, drinking water, livestock watering and irrigation. The study expects for a strong growth in the coming 15-year of withdrawals of surface water in the basin. The total removal passes from 6.4 to 28.8 billion m³. This expected growth of withdrawal is strongly related to:

- Expected herd of about 85% growth
- Expected growth of the basin's population of around 70%
- Expected growth of the irrigated area under total control of nearly 500%.

The growth of 1.3 million hectares of irrigated area under total control corresponds to a maximum scenario whose feasibility remains to be analyzed, especially in terms of water resources. It is important to notice the current study has taken into account the water consumption for hydro-electricity production which might increase significantly with the planned future dams (Fomi, Taoussa and Kandandji).

The challenges of water withdrawals from the surface waters of the Niger River Basin are:

- Sharing water in the basin: consideration of upstream and downstream needs and environmental needs in the decision to increase the withdrawals,
- Improved knowledge of samples: installation of meters to the right of withdrawals, update the database on withdrawals across the basin.
- Sharing of knowledge on withdrawals
- Improving the efficiency of water use: reducing leakage in networks and better management of irrigation systems.

(b) Water use at the Inner Niger Delta scale

The main uses of water resources in the area of DIN are: irrigation (total control and controlled flooding), the supply of drinking water to the people for their different needs (drink water, and other uses) and watering livestock (Zwarts et al., 2005).

These are the offices of agricultural development as the Office du Niger, Office Riz Segou and Office Riz Mopti who consume the most water.

Office du Office consumes 2.6 km ³ of water for irrigation of about 85,000 ha. During the years of high flood, the water consumption is 3% of the total flow and 16% during years of low floods. The majority of this water is used for irrigation of sugarcane (18,200 m³/ha/year) against 14,000 m³/ha/year for rice.

The management of Markala dam has then a significant impact on a substantial flow of the Niger River, especially during low water. Given the enthusiasm of farmers in the Office du Niger area for off season cropping seasonal water shortages are becoming more common resulting with the total drying of the river after the close of the dam sluices Markala. To overcome this situation, the Water Management Commission of Selingue and Markala dams has set a 40 m³ / s to ensure the minimum flow downstream Markala by the Office of Niger to cover the water needs of riparian populations and ecological needs of the Inner Niger Delta. It is clear that this flow threshold have not been respected by the Office du Niger for a while. The water withdrawals upstream the Inner Niger Delta and the extension of the Office du Niger lead to a reduction of flood areas of the IND about 1700 km ² at the expense of productions of fish, rice and animal of the IND.

Office Riz Mopti (ORM).manages a usable surface AREA under controlled flooding of 33,820 hectares. This infrastructure needs about 240 million m³/year. Also, ORM manages 635 ha of Small Irrigated village Perimeters villagers and an average surface of 500 ha in total control of water.

Supply of drinking water: The city of Mopti, the main city of IND consumes daily basis 9700 m³/day taken from the Niger River by EDM-SA

(c) Stakeholders and stakeholder platform at the Niger River basin scale [section written based on BRL and DHI, 2007a/b, PADD phase1/2, NBA]

Prime stakeholders are the member States of the Niger River and the Niger River Authority Basin (NBA), whose purpose is to promote cooperation among member countries and ensure integrated development of the basin by the development of its resources, particularly in the areas of energy, water resources, agriculture, livestock, fisheries and aquaculture, forestry and logging, transport and communications and industry. A precursor and catalyst event to the implementation of IWRM in the basin of the Niger River in the NBA has been the Paris Declaration signed in 2004, a statement on "The principles of management and good governance for sustainable development and shared Niger Basin " by nine heads of State and Government (Benin, Burkina Faso, Cameroon, Chad, Côte d'Ivoire, Guinea, Mali, Niger, Nigeria). At the same time, a "clear and shared vision" of the Niger Basin has been developed to create an "enabling environment" for cooperation and to prepare a "Sustainable Development Action Plan (SDAP)," accepted by all stakeholders in the basin.

The "Shared Vision" is a political statement which reflects the strong commitment of states for a common agenda. It consists of an overview of the development of the basin negotiated and accepted by all member states. The Shared Vision aims to promote understanding, strengthen cooperation between the States and make the best sustainable use sources of the basin.

The second step was the adoption of the SDAP and Investment Plan by the meeting of Heads of State at Niamey in 2008. Under the SDAP for the integrated water resources management in the basin of the Niger River, the NBA has developed several tools: among others, Niger Basin Observatory, the Water Charter of the basin, implemented several programs and projects whose ultimate goals are IWRM the establishment of National Commissions of water resource users of the Niger River and the Regional Commission of Water Resources Users, and support the process of political dialogue on the major existing and future dams on the Niger River:

- **Water Charter:**

The adoption of the Water Charter is a legal and regulatory reference document for the concerted and sustainable management of water resources of the Niger Basin. The Charter was ratified by 8 of the 9 countries and entered in force since July 19, 2010. The main challenges facing the Water Charter are: its dissemination through all over the basin and its adequate implementation.

- **Niger Basin Observatory**

NBO helps to strengthen the coordinating role of the NBA and improve coordination across the basin. The long-term objective of the NBO is to follow through the establishment of a network, the evolution of the environment in the Niger basin. It is able to monitor and measure changes and provide stakeholders and decision makers with the necessary information to inform decision making. It will be a tool for strategic and operational decision making.

- **National Commission for users of water resources and Regional Commissions users of water resources**

During the 25th Ordinary Session of the Council of Ministers of the Niger Authority, held in September 2006 in Niamey, it was adopted a resolution on the involvement of civil society in the process of the Shared Vision. The concept of civil society refers to all collective actors "users of natural resources" in the Niger River Basin and are active at local, national and regional basin according to their own formal or informal modes of organization and whose action or activity has a direct and / or indirect impact on the natural environment, political and socio-economic basin. For this purpose, 9 national coordinations and one regional coordination of users of natural resources of the Niger Basin (involvement of the civil society) have been established.

The challenges facing this new platform are:

Governance:

- A civil society unengaged and not represented at all levels of the basin for effective participatory to decision-making
- Lack of information and awareness of civil society on how and when to begin their involvement in the management of natural resources

Information: civil society does not have access to all the knowledge to engage as a peer and decision making

Commitment capacity: Lack of human and financial resources to participate meaningfully in decision-making regarding the management of the Niger River Basin Natural Resources. **Ability to speak with one voice:** the challenge for civil society to agree on key issues, issues and common agreements for better participation in discussions and negotiations, making them weak or no voice

- **Support to the development of IWRM Action Plan:**

NBA through his expertise and 9 national focal offices have supported several of its member countries to develop their IWRM (Integrated Action Plan for Water Resources Management). For this purpose, Mali and Burkina Faso have adopted and validated their action plans, Cote d'Ivoire and Nigeria have validated but not adopted, Guinea has an existing road map for elaboration.

- Monitoring and management of water resources
- Reversing land and water degradation trends in the river Niger basin‘‘
- Silting Control Program in the Niger Basin
- Water Resources Development and Sustainable Ecosystem Management Program
- Support for the establishment of an Environmental Observatory of the Niger Basin"
- NBA Capacity building
- Support to the Management of groundwater in the Niger Basin
- Use of satellite hydrology

- **Dialogue on dams in the Niger River Basin.**

The report, Regional Dialogue on large water infrastructure in West Africa: Building multi-stakeholder participation from 2009 to 2011 is published by IUCN in partnership with the Water Resources Coordination Centre (WRCC) of Economic Community Of West African States (ECOWAS). It describes the various steps and progress of regional consultation, with the objective of contributing to the sustainable development of West African regional integration. The report also elaborates on the development of tools to support investment plans in a coordinated framework. Since the publication of this report, IUCN and IIED are about to facilitate a stakeholder platform (CNU CRU managers dams, policy makers at all levels) to implement the recommendations of the various meetings on existing dams and future of the rivers of West Africa

b) Stakeholders and stakeholder platform in the Inner Niger Delta

Apart from OPIDIN stakeholder platform which was the object of further description in previous chapter as well in the deliverable 4.8, we can also outline two main water user platforms:

- **The cooperative of rice farmers**

The cooperative is the link between all the rice farmers in the IND and the Office du Riz Mopti. It takes great care of the dates of entering of water enters in rice fields, depending on water levels in the Niger River and according to their toposequence (high or low parts) and manages all disputes with ORM.

- **Water Management Commission of Sélingué and Markala dams**

Committee Missions

- Examine the programs of national water management structures benefiting from water dams and ensure their adequacy;
- Review and advise on the future expansion of irrigated areas;
- Developing programs of water management Sélingué dam and monitor their implementation
- Inform decision makers about the impact of water management of the dam in all aspects of activities related to the dam;
- Propose penalties for non-compliance with management guidelines;
- Encourage users to provide timely withdrawal data and water needs
- Help enforcement the principle withdrawer- payer
- Help set a volumetric charge for water collection;
- Ensuring the optimization of water management through the promotion of water-saving techniques in irrigated areas;

Achievements of the Commission

- Development of a curve for better water resources management
- Development of management guidelines
- Signing of cooperation agreement for sharing the water resources of the channel of Baguineda;
- Annual Arbitration for sharing the water resources of the Sankarani river between ODRS and EDM-SA for supplying water in priority to Manikoura perimeter since 2008;

- Compliance with management guidelines which apply to all stakeholders including the guaranteed rate of 40 m³/s downstream Markala by the Office du Niger and the curve of water management Sélingué dam by EDM -SA.

Challenges of the Commision

- Lack of operating budget
- Cover the growing needs of irrigation water during low flow while respecting the guidelines 40 m ³ / s downstream Markala dam;
- Increased demand for water for agricultural needs and high variability of the resource in the context of Climate Change ;
- Monitoring of water samples;
- Prevention of conflicts between water users;
- How to produce more with little water;
- Making allocation model of water resources

4.1.2 Current forecast, early warning and preparedness in place from regional to local levels

(a) At the regional level

Many regional institutions are helping the different countries to forecast and to be prepared for recurrent droughts in the region. Amongst these institutions could be primarily cited:

- **ACMAD (African Center of Meteorological Application for Development)**

Established in 1987 by the Conference of Ministers of the Economic Commission for Africa (UNECA) and the World Meteorological Organization, the African Centre of Meteorological Applications for Development brings together 53 African countries. ACMAD is based in Niamey, NIGER, since 1992.

Objectives:

- Contribute to sustainable development of the various socio-economic sectors of Africa
- Make weather, climate and environmental resources for sustainable development

Fields of action:

- Food security
- Water resources
- Health
- Protecting the environment
- Civil Security
- Renewable energy

Activities

- Development and transfer of tools and technologies to NMS (National Meteorological Systems)
- Transmission of weather and climate information to users especially in rural areas.
- Showcase to the technology partners under the usual conditions of Africa.
- Amplifying the impact of the activities of Member States and partners
- Development of information and products on the weather and climate for sustainable development

Products

Weather Watch:

- Flood risk bulletin for the 53 member countries
- Severe weather forecasting: prediction of high-impact weather conditions. This bulletin provides a forecast three days of the occurrence of six high-impact meteorological phenomena: heavy rain, strong wind, very high temperature, very low temperature, dust or sand and wave

- Weekly monitoring and forecast: i.e. Bulleting of heavy rain,
- African Monsoon bulletin

Climate and Environment:

- Weekly bulletin: climate and health
- Decadal climate bulletin
- Bulletin on climate and health

ACMAD also helps to strengthen the capacity of **universities and research institutes** from 54 member states in the field - Climate Prediction - technologies (Telecommunications, computer etc.). As part of the partnership between the **Niger Basin Authority** and the African Centre of Meteorological Applications for Development (ACMAD), two projects are joint financing by AFD (Agence Française de Développement) and FFEM (Fonds Français pour l'Environnement Mondiale) and are followed by the agency Niamey. The first project supports in the acquisition process, processing, and modeling data for efficient management of water resources in the Niger River Basin (IWRM 2). The second is to support the implementation of vigilance systems to climate change in Africa.

- **The Permanent Interstate Committee for Drought Control in the Sahel (CILSS)**

The CILSS is an intergovernmental organization established in 1973. It was set up by nine Sahelian countries: Burkina Faso, Cape Verde, Gambia, Guinea Bissau, Mali, Mauritania, Niger, Senegal, and Chad. CILSS is structured in three sites:

- the Executive Secretariat (Ouagadougou - Burkina Faso)
- the Sahel Institute INSAH (Bamako - Mali)
- the AGRHYMET (Niamey - Niger)

- **The AGRHYMET Regional Center (CRA)**

The CRA based in Niamey is a specialized agency of the CILSS (Permanent Inter-State Committee for the Fight against the Fight against Drought in the Sahel) which provides support to the Regional Programs developed by CILSS in 9 member countries on:

- Food security and the fight against desertification
- The water management
- The promotion trade in agricultural products
- The three main missions of AGRHYMET are:
- **Information:** In conjunction with the national components, the CRA periodically broadcasts newsletters (decadal, monthly, seasonal) for: the course of the rainy season, the hydrological monitoring of river basins and dams, the development of crops and pastures, the cereal and food balance sheets, the pest monitoring (including locust) and changes in prices of agricultural products
- **Research:** Development of methods and techniques for monitoring food security and natural resource management and Receiving and processing of satellite images, preparation of maps and geographic information systems
- **Training:** Since its inception, the center has graduated more than 950 officials from member countries (senior technician and engineer cycle) in agro-meteorology, hydrology, Plant Protection and maintenance of instruments, Since 2007, students can follow a master of the Concerted Management of Natural Resources) and The training sessions helped to transfer acquired tools and methodologies to more than 5,000 African professionals

- **The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT)**

ICRISAT is a non-profit, non-political organization that conducts agricultural research for development in the drylands of Asia and sub-Saharan Africa. Covering 6.5 million square kilometers of land in 55 countries, the semi-arid or dryland tropics has over 2 billion people, and 644 million of these are the poorest of the poor. ICRISAT and its partners help empower these poor people to overcome poverty, hunger and a degraded environment through better agriculture. ICRISAT is headquartered in Hyderabad, Andhra Pradesh, in India, with two regional hubs (Nairobi, Kenya and Bamako, Mali) and country offices in Niger, Zimbabwe, Malawi, and Mozambique. ICRISAT conducts research on five highly nutritious drought-tolerant crops: chickpea, pigeonpea, pearl millet, sorghum and groundnut

- **Seasonal forecast rainfall and runoff in West Africa (PRESAO).**

The PRESAO initiative (seasonal forecast in West Africa) was launched in 1998 by a consortium including the African Centre for Meteorological Applications Development (ACMAD) AGRHYMET and the Niger Basin Authority. PRESAO aims capacity building in the field of seasonal climate prediction

- **HYCOS-AOC**

The Niger Basin and AGRHYMET are carrying out since January 2000 the pilot phase **HYCOS-AOC** which is the African component of the **Western World Hydrological Cycle (WHYCOS) of World Meteorological Organization observation system**. It covers 11 countries (Benin, Burkina Faso, Cameroon, Côte d'Ivoire, Ghana, Guinea, Mali, Niger, Nigeria, Senegal and Chad).

- **FRIEND** (Flow Regimes from International Experimental and Network Data).

FRIEND- West and Central Africa is part of West Africa and Central FRIEND project (Study of Flow Regimes from International Experimental and Network Data). This project is a component of the IHP (International Hydrological Program) of UNESCO which is another initiative related to the hydrological cycle. Its main objective is to promote scientific research on the water cycle through the creation of a network of researchers working in this field.

- **Assessment of Impacts and Adaptations to Climate Change (AIACC)**

Launched in February 2002, AIACC is an initiative of the Intergovernmental Panel on Climate Change mainly financed by the Global Environment Fund. Its objective is to advance research on climate change in developing countries with particular emphasis on adaptation.

Finally, previous deliverables inventoried in details other institutions and scientific initiatives in the Niger Basin more particularly in Mali linked to drought hazard (Cf. description of GIEWS/SMIAR, University of Princeton, FEWS NET, ROSELT, AMMA, HYDRONIGER, SPIAC, INSAH, etc… in D6.1 T6.4 and D5.4).

(b) At the national level

- **Early Warning System (SAP)**

SAP provides the necessary information for an optimal allocation of national food security stock in the context of targeted operations or efficient situation of food security fund in mitigation of food insecurity "actions food aid “.This is the essential mission of the Early Warning System (EWS) which is a system of permanent collection of information on the food situation. The mission of the SAP is to "prevent in early manner, the CTCPSA (Technical Committee Policy Coordination for Food Security) the occurrence of any form of food crisis and / or nutritional a specific geographic level, and propose measures likely to mitigate the effects.

This mission has three components:

- Permanent and very thin monitoring in areas potentially at risk of a food crisis, timely monitoring and following a slight methodology in the area south of the 14th parallel
- Targeting early manner on population groups at risk of experiencing food crises
- Recommendation on food or alternative interventions to mitigate the effects of difficulties or food crises.

- **The National Agency of Meteorology** is responsible for the observation and study of weather, climate and atmospheric components of the environment to ensure the safety of persons and property and contribute to economic and social development of Mali by providing appropriate information and services to all users. It participates in the development of elements of the national policy of Meteorology and ensures the implementation and monitoring.

(c) At the Inner Niger Delta level

Apart from the initiatives already well detailed in WP6-D6.1-T6.4 and WP5-D5.4, DEWFORA project participated in developing the OPIDIN tool to predict flood in the Inner Niger Delta (**OPIDIN**). With the initiative of **the National Directorate of Water in Mali in collaboration with a consortium of Dutch institutions,** OPIDIN allows farmers, herders, fishermen, sailors and boatmen, etc. in the Inner Niger Delta (all members of the Regional Chambers of Agriculture) to already know in August / September through the Regional Directorate of Hydraulics appropriate information about flood peak and flood receed. The work developed under DEWFORA was the object of one chapter in WP4-D4.8 and in this deliverable at section 3.3

4.2 VULNERABILITY ASSESSMENT TO DROUGHT

4.2.1 Method investigated to assess the vulnerability of water uses to flood regime variability in the Inner Niger Delta with SWIM outcomes

The illustrations below present the main sectors in the Inner Niger Delta subject to vulnerability during drought periods. Water scarcity is also the main source of tension and competition for land and water use among the different stakeholders in which each activity are also originally strongly linked to ethnic groups.

Figure 59: Competition and tension between the main water use in the Inner Niger Delta

This section aims to present the current advancement in the methods investigated to assess the vulnerability of water uses to flood variability. Free submersion farming, fishing as well as pastoralism and biodiversity were examined according to the variability of the hydrological regime. Finally, another section presents the uncertainties for the selection of socio-economic indicators (such as population growth and consumption habit) especially for long term projections prospective.

(a) Free submersion farming: Floating rice or cultivated rice (Oryza glaberrima) (Figure 60)

Liersch, S., et al. 2005 assessed the vulnerability of rice production in the Inner Niger Delta to water resources management under climate variability and change. Based on the statistical climate model STAR, impacts of existing and planned upstream dams on food demands and supply in the Inner Niger Delta (floating rice) under different climate and population growth scenarios for the period 2011-2050 was investigated.

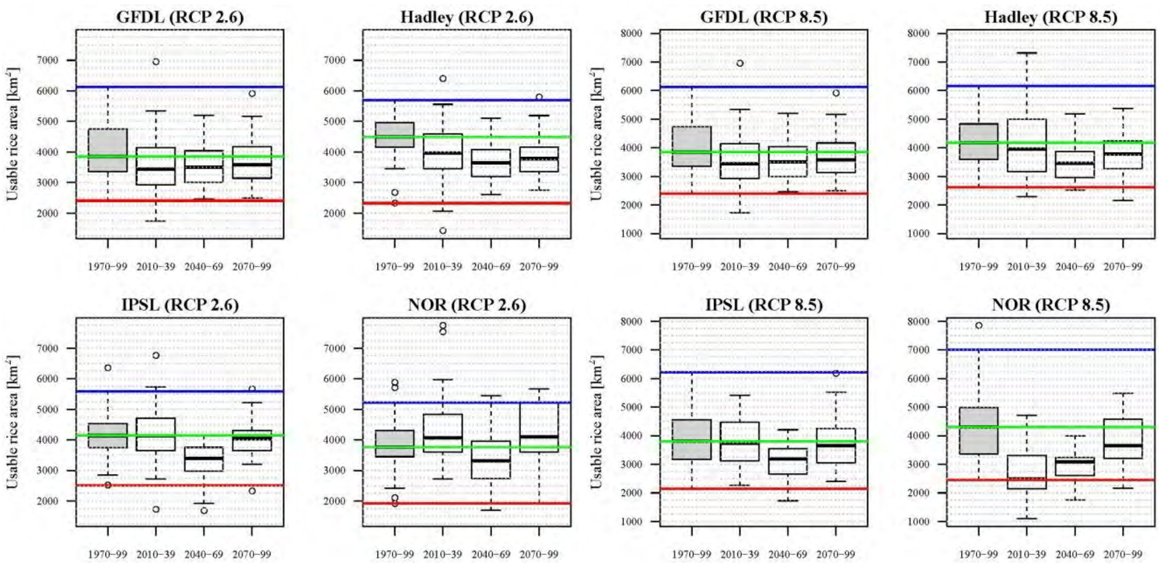
Figure 60: Flooding plain in the Inner Niger Delta with floating and cultivated rice plantation

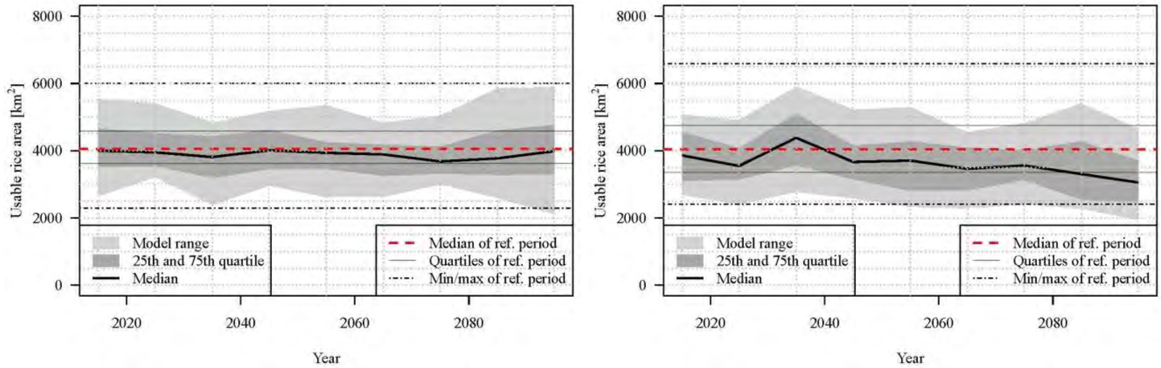
With the support of SWIM model and it inundation module developed to represent the flood propagation in the delta, the simulated inundated area respecting three physical and hydrological conditions to grow floating rice was considered each year to assess the potential usable area to grow floating rice. Therefore, the area standing on clayey soils with water levels standing between 1 to 2.5 meters and with a duration of at least 90 days were assessed assuming a productivity of 2 ton per ha. This method relating the annual evolution of the usable area for floating rice with optimal flood parameters is applied with new upstream water ressources management and climate change projections scenario (see Chapter for more details).

It is important to notice that this method still neglects many important aspects:

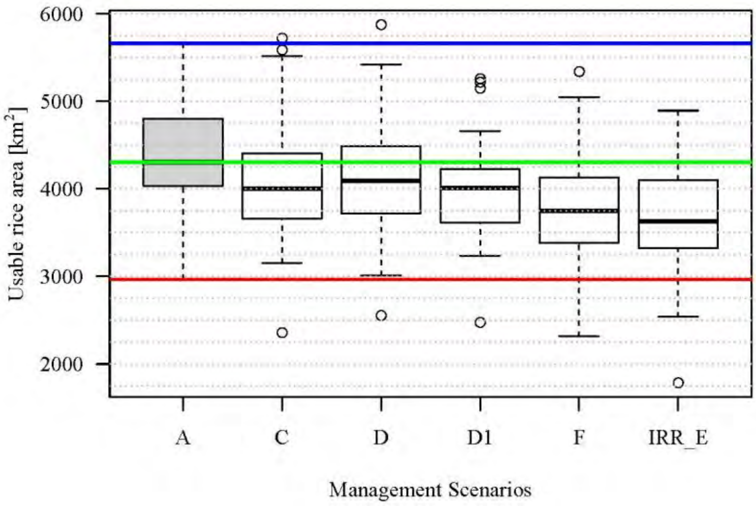
- The success of the seeding depends largely to an optimal occurrence of the first rainfall.
- Potential area for floating rice are only potential due to the resolution used in this study also as some plots are certainly used for other objects or are simply not accessible to launch this activity.

The next set of figures show the impacts of climate change scenarios RCP 2.6 and 8.5 (four ISI-MIP ESMs) on potentially usable areas for floating rice production. The first (grey) boxplot shows the distribution of usable areas in the reference period. The blue line indicates the maximum, the green line the median, and the red line the minimum area during the reference period (extreme outliers are ignored here).





Figures 61: climate change impact on usable area for floating rice (Scenario B RCP 2.6 (Left) and RCP8.5 (Right))



Figures 62: climate change impact on usable area for floating rice according to different upstream water management scenario settings

(b) Fish sector

Numerous publications studied fisheries in the Inner Niger Delta (Welcomme, 1986, Quensiere et al., 1994, Lae, 1995, Zwarts et al. 2005) and the impact from hydrological variabilities and upstream dams. Zwarts et al. (2005) found a strong statistical relation between the annual variations of fish catches measured by Office de Peche Mopti (OPM) with the preceding maximum annual flooded area in the Inner Niger Delta evaluated with satellite imagery. In Figure 63, we show that we can even obtained a better correspondence (R^2 of 0.74 instead of 0.71) when we built a similar statistical regression using a 2nd order polynomial relating annual fish catches with the preceding annual inflow entering the delta from the Niger and the Bani rivers simulated with SWIM. This statistical function is then further applied with SWIM hydrological outcomes to assess the evolution of fish catches across the different scenario established in the chapter 3.2.1.

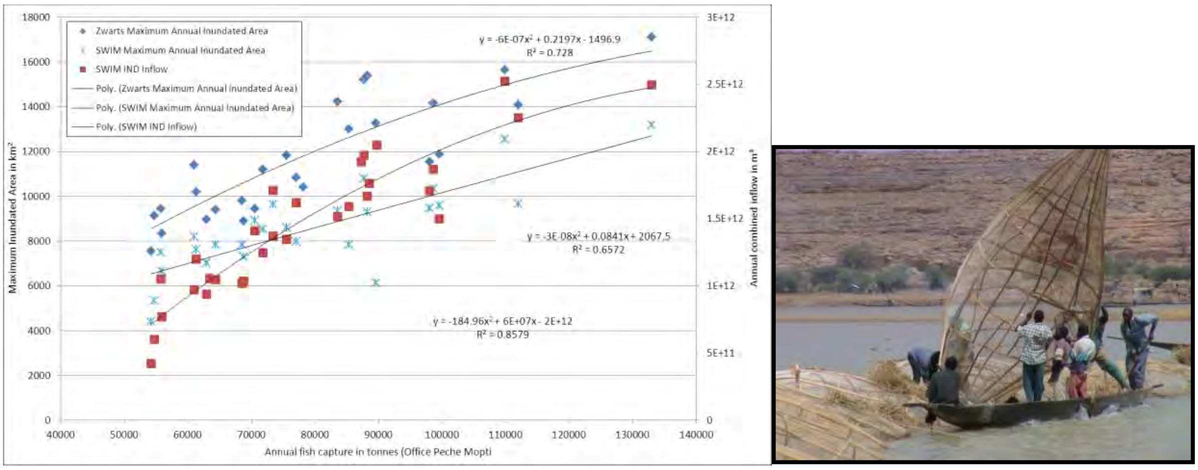


Figure 63: Statistical regression between maximal inundated area and annual fish catches in the Inner Niger Delta. Source PIK and Zwarts et al. 2005 (OPM data and Photo)

Figure 64 presents the range of associated annual fish catches using also Watch Forcing Data for the different simulations in comparison to OPM´s measurement and Zwarts´s work for the period 1960-2001. Comparatively impacts on annual fish catches show more pronounced gradual decreases than maximal annual flooded surface area (Figure 50) as it loses 1.2 to 3.3 points more in percentage.

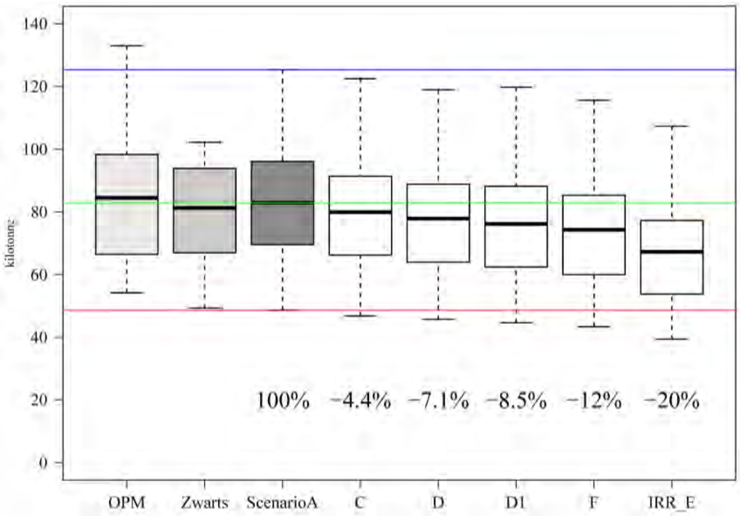


Figure 64: Distribution of annual fish catches in kiloton for the period 1966-2001: impact of simulated river basin management against measured (OPM) and Zwarts application Numbers below the boxplots indicate the change relative to scenario A (see Chapter 3.2.1)

(c) Biomass and fodder production for livestock and biodiversity

The work to associate biomass and fodder production to the SWIM simulation of the flood propagation of the Inner Niger Delta is still at an initial stage. Marie (2000) used a compilation of work from Hiernaux to build main hydrological characteristics for the 28 main vegetation formation identified in the Inner Niger Delta. PIK did a large effort to build a database relating those 28 vegetation units basis to hydrological scales as well as the associated biomass productions. The three tables in the next page based on Marie (2000) work summarized all the sub-parameters that are in the process of operational integration in the SWIM inundation module.

Vegetation Unit	Soil	Reg1	Reg2	Reg3	Reg4	Reg5	Regularity Class	Dur1	Dur2	Dur3	Dur4	Dur5	Dur6	Duration Class	Hei1	Hei2	Hei3	Hei4	Hei5	Hei6	Hei7	Water Level Class	
		Non inondée	Très irrégulière	Irrégulière	Régulière	Très régulière		Non inondée	[0-1 mois]	[2-3 mois]	[4-5 mois]	[6-7 mois]	plus de 7 mois		Non inondée	[0-0,1[	[0,1-0,3[	[0,3-0,6[	[0,6-1,5[	[1,5-2,8[	[2,8-4[		
TA	SL/ALS	4	0	0	0	0		4	0	0	0	0	0		4	0	0	0	0	0	0	1	Exondé
TB	ALS/ALS	4	0	0	0	0		4	0	0	0	0	0		4	0	0	0	0	0	0	1	Exondé
TC	SA/SA	4	0	0	0	0		4	0	0	0	0	0		4	0	0	0	0	0	0	1	Exondé
TD	SA/SA	4	0	0	0	0		4	0	0	0	0	0		4	0	0	0	0	0	0	1	Exondé
THY	ALS/ALS	4	0	0	0	0		4	0	0	0	0	0		4	0	0	0	0	0	0	1	Exondé
TS	SA/SA	4	0	0	0	0		4	0	0	0	0	0		4	0	0	0	0	0	0	1	Exondé
TT	ALS/LA	4	0	0	0	0		4	0	0	0	0	0		4	0	0	0	0	0	0	1	Exondé
AG	ALS/ALS	2	3	1	1	0		2	3	0	0	0	0		2	3	1	0	0	0	0	2	0 – 0,1 m
PAR	ALS/LA	3	2	1	0	0		3	2	1	0	0	0		3	3	1	0	0	0	0	2	0 – 0,1 m
ZB	LAS/AS	3	3	0	0	0		3	3	0	0	0	0		3	3	0	0	0	0	0	2	0 – 0,1 m
P	LA/ALS	2	3	0	0	0		2	3	0	0	0	0		2	2	3	0	0	0	0	3	0,1 – 0,3 m
PAS	ALS/LA	3	2	0	0	0		3	2	1	0	0	0		2	2	2	1	0	0	0	3	0,1 – 0,3 m
VH	ALS/LA	2	2	2	0	0		2	2	0	0	0	0		2	2	2	2	0	0	0	3	0,1 – 0,3 m
AC		0	0	3	0	0			3	3	0	0	0			1	2	3	0	0	0	4	0,3 – 0,6 m
ESP	ALS/LA	0	0	2	0	0		0	2	2	0	0	0		0	1	1	2	1	0	0	4	0,3 – 0,6 m
PAN	LA/LA	0	2	2	2	1		0	1	2	1	0	0		0	1	2	3	1	0	0	4	0,3 – 0,6 m
VSP	LA/LA	0	0	4	0	0		0	2	2	0	0	0		0	2	2	2	0	0	0	4	0,3 – 0,6 m
EOR	LAS/ALS	0	0	2	2	0		0	0	2	2	0	0		0	0	0	2	2	0	0	5	0,6 –1 ,5 m
O	LA/ALS	0	0	2	4	4		0	2	2	4	2	0		0	0	2	2	4	3	0	5	0,6 –1 ,5 m
R	LS/LAS	0	0	0	2	4		0	0	2	4	0	0		0	0	2	4	2	0	0	5	0,6 –1 ,5 m
VOR	ALS/ALS	0	0	2	2	0		0	0	2	3	2	0		0	0	2	2	3	0	0	5	0,6 –1 ,5 m
B	LA/LA	0	0	0	3	4		0	0	2	2	4	0		0	0	0	0	3	4	3	6	1,5 – 2,80 m
OP	A/LA	0	0	2	4	3		0	0	2	4	3	0		0	0	0	2	3	4	0	6	1,5 – 2,80 m
PAM	ALS/ALS	0	3	2	0	0		0	0	0	2	3	2		0	0	0	0	2	3	2	6	1,5 – 2,80 m
VB	AS/ALS	0	0	2	3	2		0	0	0	2	3	0		0	0	0	2	2	3	2	6	1,5 – 2,80 m
BP	LA/LA	0	0	0	3	4		0	0	0	2	4	3		0	0	0	0	2	3	4	7	2,80 – 4 m
PAK	ALS/L	0	0	0	2	4		0	0	0	0	2	4		0	0	0	0	0	2	4	7	2,80 – 4 m
MB	ALS/ALS	0	0	2	3	4		0	1	2	2	3	0		0	3	3	3	3	3	2	2 to 6	2,80 – 4 m

Vegetation Unit	Annual production			ses feuillées de Dé			tion journalière avec fauches répétées tous les 1									Végétaux	isponibilités fourragères saisonnières des ligneux en kg MS/				
	Min	Mean	Max	Min	Mean	Max	Oct.	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun		Jun. Jul.	Aug. Sep.	Oct. Nov.	Dec. Jan. Feb.	Mar. Apr. May
TA	3000	5000	8000	300	600	1 200	0	0	6	5	4	2	0.5	0.3	2	0	0	0	0	0	0
TB	2500	4000	8000	0	0	0	0	0	0	0	0	0	0	0	0	350	225	350	250	175	100
TC	15000	20000	30000	3000	6000	10000	0	0	10	10	30	60	50	30	30	0	0	0	0	0	0
TD	10000	20000	35000	2500	5000	10000	0	0	0	10	25	50	50	25	10	0	0	0	0	0	0
THY	3000	8000	12000	400	750	1200	0	0	12	5	3	2	1.5	1	0.5	0	0	0	0	0	0
TS	3000	5000	8000	100	400	1000	0	4.5	3.25	2.75	2.5	1	0.5	0.5	3	0	0	0	0	0	0
TT	6000	9000	15000	800	1200	1800	0	0	10	8	8	5	4	3	1	0	0	0	0	0	0
AG	1500	1900	2900	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PAR	5000	8000	15000	400	800	1200	0	10	8	4	2	1.5	0.75	0.25	13	0	0	0	0	0	0
ZB	3000	6000	12000	300	900	1500	0	0	6	3	2	2	1	1	15	0	0	0	0	0	0
P	3000	5000	8000	100	250	600	0	0	4	2.5	1	0.5	0.25	0.25	4.5	0	0	0	0	0	0
PAS	10000	15000	25000	2500	5000	7500	0	0	0	0	0	25	50	50	25	175	100	0	0	75	225
VH	2000	4000	8000	500	750	1500	0	0	0	5	4	3	3	5	8	800	500	575	500	375	250
AC	300	700	1800	0	0	0	0	0	0	0	0	0	0	0	0	2000	650	2000	1850	1300	1000
ESP	500	1000	2500	0	0	0	0	0	0	0	0	0	0	0	0	250	125	250	200	250	200
PAN	300	800	2500	0	0	0	0	0	0	0	0	0	0	0	0	250	100	250	125	100	60
VSP	1500	3000	6000	0	100	1000	0	0	0	1.5	1	2.5	3	4	5	0	0	0	0	0	0
EOR	2500	3750	5000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
O	2000	3000	6000	0	0	0	0	0	0	0	0	0	0	0	0	650	200	600	500	250	125
R	800	1500	3500	0	0	0	0	0	0	0	0	0	0	0	0	550	200	550	200	100	75
VOR	500	1500	3500	0	0	0	0	0	0	0	0	0	0	0	0	650	250	500	400	500	250
B	200	400	1500	0	0	0	0	0	0	0	0	0	0	0	0	1400	1100	1400	1200	1500	600
OP	300	800	1500	0	0	0	0	0	0	0	0	0	0	0	0	550	200	500	250	100	75
PAM	300	500	1500	0	0	0	0	0	0	0	0	0	0	0	0	3000	1750	2250	2650	3000	1400
VB	1200	1800	3000	0	0	0	0	0	0	0	0	0	0	0	0	175	100	175	100	50	25
BP	8000	12000	20000	500	1500	3000	0	0	0	0	8	6	5	10	15	0	0	0	0	0	0
PAK	5000	8000	12000	200	600	1000	0	0	4	3	4	1	1	0.75	2.5	0	0	0	0	0	0
MB	7000	10000	15000	1500	1800	2500	0	0	15	13	12	10	4	6	2	0	0	0	0	0	0

Water Level Class	Water Level	Vegetation group
7	]2,8 m à 4 m]	BP - PAK
6	]1,5 m à 2,8 m]	B - OP - VB - PAM
5	]0,6 m à 1,5 m]	EOR - O - VOR - (R)
4	]0,3 m à 0,6 m]	AC - ESP- VSP- PAN
3	]0,1 m à 0,3m.]	P - VH - PAS
2	]0 m à 0,1 m]	AG - ZB - PAR
1	exondé	TA - TS - TB - TC - TD - THY- TT

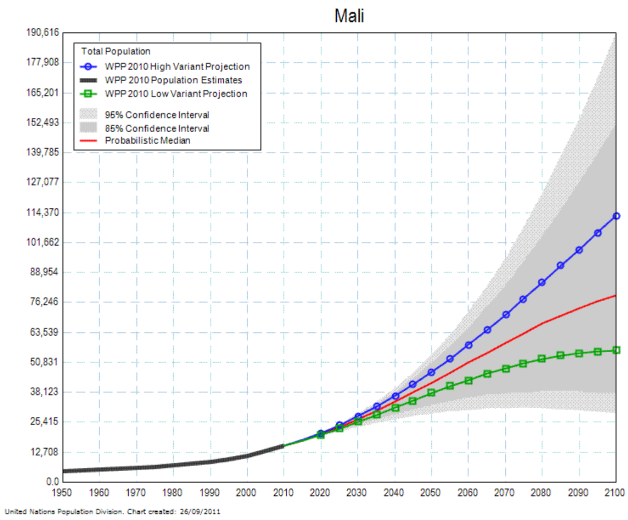
Soil profil (1st+2nd layer)	A/LA	LA/LA	ALS/LA	ALS/L	LA/ALS	AS/ALS	ALS/ALS	LAS/ALS	SL/ALS	LAS/AS	LS/LAS	SA/SA
Exondé			TT				TB THY		TA			TC TD TS
0 – 0,1 m			(PAR)				AG (MB)			ZB		
0,1 – 0,3 m			VH (PAS)		P		P (MB)					
0,3 – 0,6 m		(PAN)* VSP	ESP				(MB)					
0,6 –1 ,5 m					O		VOR (MB)	EOR			R	
1,5 – 2,80 m	OP	B				VB	PAM (MB)					
2,80 – 4 m		BP		PAK								

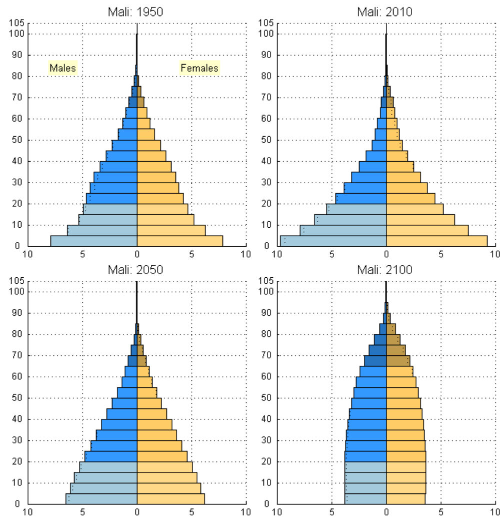
Tables 9, 10 and 11: summary of the building of a biomass and fodder production ecosystem database for SWIM application in the Inner Niger Delta based on Marie (2000)

(d) Population growth

Liersch et al., 2005 considered two population growth scenarios for the Inner Niger Delta in order to assess the demands for rice production of a growing population respectively 0.7% (Zwarts et al., 2005) and 2.65% (PDD-DIN, 2011). A review of demographic projections will permit to identify the range of population growth and deliver more realistic range.

The two figures below present the 2010 to 2100 projection for the population growth and it pyramidal structure in Mali according to UN-Population Division. The first chart shows estimates and projections of the total population for Mali in 2010. The projections are based on the probabilistic fertility projections from the 2010 Revision of the World Population Prospects. These probabilistic projections of total fertility had been carried out with a Bayesian Hierarchical Model. The figures display the high, medium and low variant of the 2010 Revision of the World Population Prospects, as well as the probabilistic median and the 95 as well as 80 per cent confidence intervals of the projections. In the second chart, the population by age groups and sex (percentage of total population in Mali is presented in four periods (past, present and two projected. The dotted line indicates the excess male or female population in certain age groups. Age groups are in per cent of the total population in 1950, 2010, 2050 and 2100, respectively.





Figures 1 and 2: UN Division population 2010 projections: evolution of the population structure and growth in Mali

Source Left Chart: United Nations, Department of Economic and Social Affairs, Population Division (2010): Population projections using probabilistic projections of total fertility and life expectancy at birth, based on a Bayesian Hierarchical Model (BHM). New York (internal data set)

Source Right Chart: United Nations, Department of Economic and Social Affairs, Population Division (2011): World Population Prospects: The 2010 Revision. New York

The figure below is the results of a work achieved in the Niger Basin Focal Project. The maps represent the correlated population density dynamic in the Niger River Basin according to the low variant of the UN Population Division 2010 above scenario.

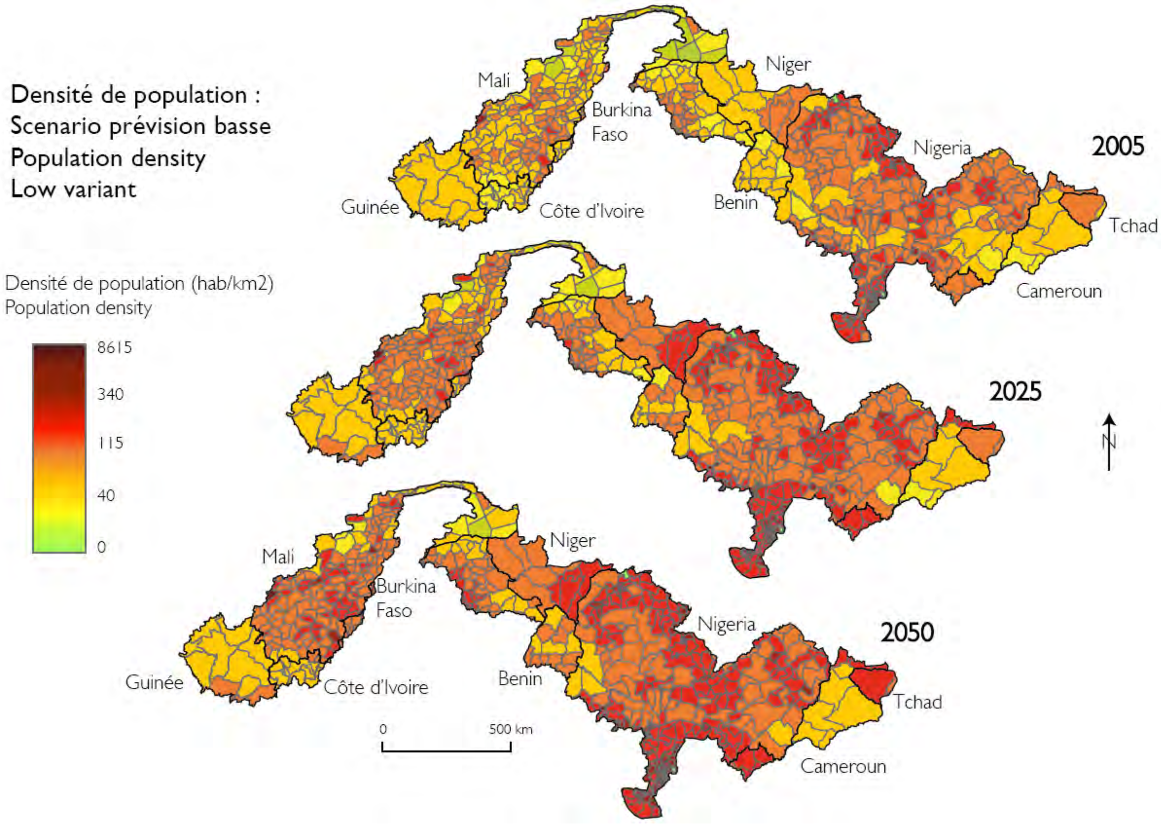


Figure 3: population density Low variant UN Division population 2010 projection Source: Clanet, Jean-Charles, and Andrew Ogilvie. 2009. Synthesis Report. CPWF Working Paper. Niger Basin Focal Project Series. Colombo, Sri Lanka: The CGIAR Challenge Program on Water and Food.

To assess progressive demographic projections restricted to the eight cercles of the Inner Niger Delta (Macina, Diré, Niafunke, Goundam, Mopti, Djenné, Ténenkou, Youvarou) which preserve local demographic characteristics, we applied to the UN population division demographic population of Mali a regional bias correction as followed. First, the mean annual growth of the population for the three given periods (1976-1987, 1987-1998 and 1997-2009) were collected from the four National Malian population census of the eight cercles (1976, 1987, 1998 and 2009) and also from the UN population division demographic projections of Mali. The difference between the regional and the UN mean annual growth is of -1.08 points between 1976-1987, -1.79 points between 1987-1999 and -0.34 points between 1999-2009. This negative bias can be interpreted as the consequence of local demographic characteristics and of the effects of internal migration in the country (drift away from land, urban polarization). We applied then this bias to the UN population division demographic population for each intercensus period and we finally make the assumption to use the most recent regional bias (-0.34) for future projections. This assumption might be taken with extreme caution as the future dynamics of population in the Inner Niger Delta will be maybe driven driven by new phenomena (drift away from the land, drought hazard and emergence of conflict) which can disrupt the regional demographic evolution. The results are plotted in Figure 65 with the demographic assumptions made in Liersch et al. (2005). We can then see that the PDD-DIN scenario (2.65% Mean Annual Growth) is in line with the regional bias UN demographic projection Moderate. However, the assumptions based on Zwarts (2005) (0.7%) seems completely out of the range. The use of a regional bias correction application on the UN population demographic division permits to consider regional pattern and particularities in the evolution of the population which are in line with national demographic projection standards from international organisations. The range of population in the Inner Niger Delta (from Low to High variant) is between 3.4 to 4.1 Millions in 2050 and between 4.2 to 8.5 Millions in 2100.

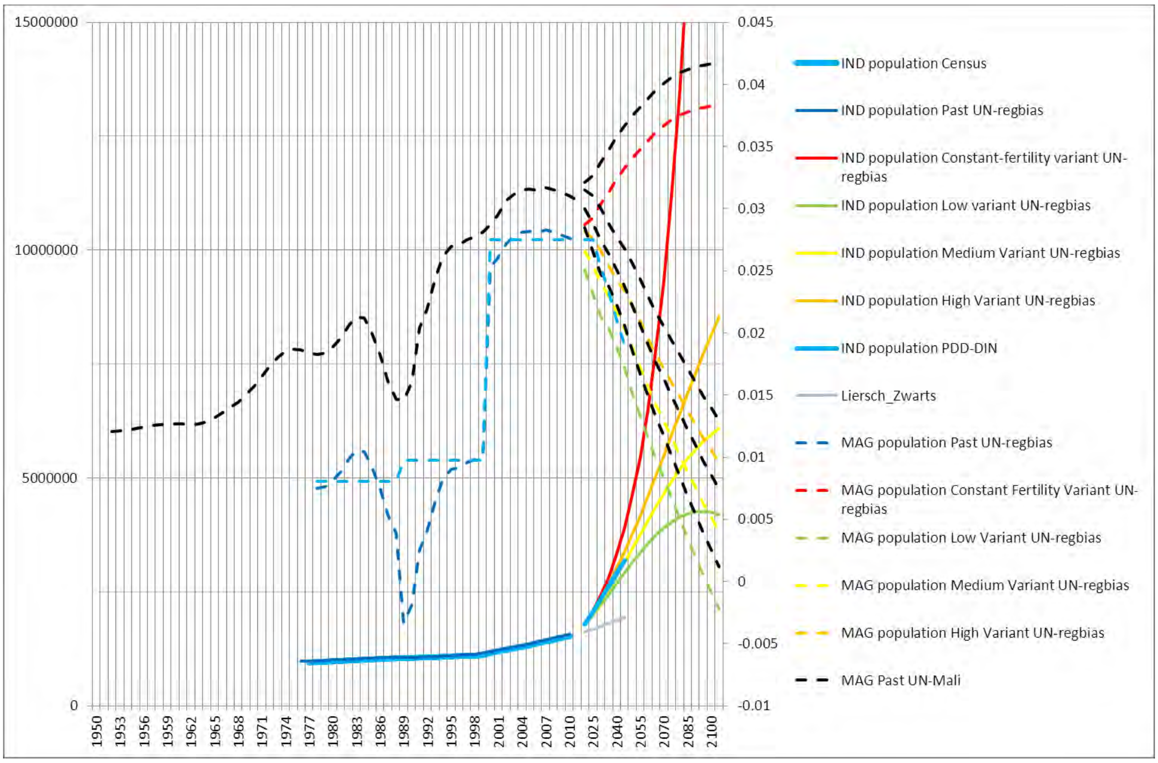


Figure 65: Application of regional bias to UN population division projections from Mali in the Inner Niger Delta (IND): Left axis represent capita and the right Mean Annual Growth in % (0 to 1)

(e) Regional food demand

In Liersch et al. (2005) and Marie et al. (2007), the cereal consumption in Mali is respectively considered to be about 214 and 204 kg/person/year. To consider regional food demand in line with population growth, this section deepen the study of the food demand assessing more in details the contribution and the progression of specific staple products in the diet regime in Mali and in the Inner Niger Delta. The objective is to improve the selection of food demand criteria to setup vulnerability assessment to food security and to assume uncertainties when selecting indicators to identify the future regional demand for rice, meat, fish and milk in the Inner Niger Delta.

According to EMEP (2003), the regional consumptions in the Inner Niger Delta (district of Ségou, Mopti and Tombouctou) per capita and per annum for the main food commodities strongly differ from the national consumption pattern. It is respectively 85.2 and 52.7 kg, 7.5 and 8.3 kg for beef, 13.6 and 7.6 kg for fish, 13.6 and 8.5 kg of milk for the regional and national consumption. The EMEP statistics given for Mali differs also from the international FAO statistics (mean form 1996 to 2001) especially for milk with respectively 44 kg for rice, 14.9 kg for meat, 8.8 kg for fish and 46.9 kg of milk per capita and per annum.

To integrate the problematic of food security and regional self-sufficiency for food in a vulnerability assessment, assumptions made in the selections of mean annual food supply per capita for staple products can generate large uncertainties. Coupled with demographic projections, the change of 1 kg in a food demand criteria for a given product can create exponential increase. Uncertainties are higher if we consider that we neglect future evolution of the diet regime for long term projection from 2010 to 2100. Figure 66 shows the historical evolution of the total energy, protein and fat consumption in Mali according to FAO statistics. The total energy consumption pass from 2000 to 2500 Kcal/pers./day between the sixties to mid-eighties and the mid-eighties to present.

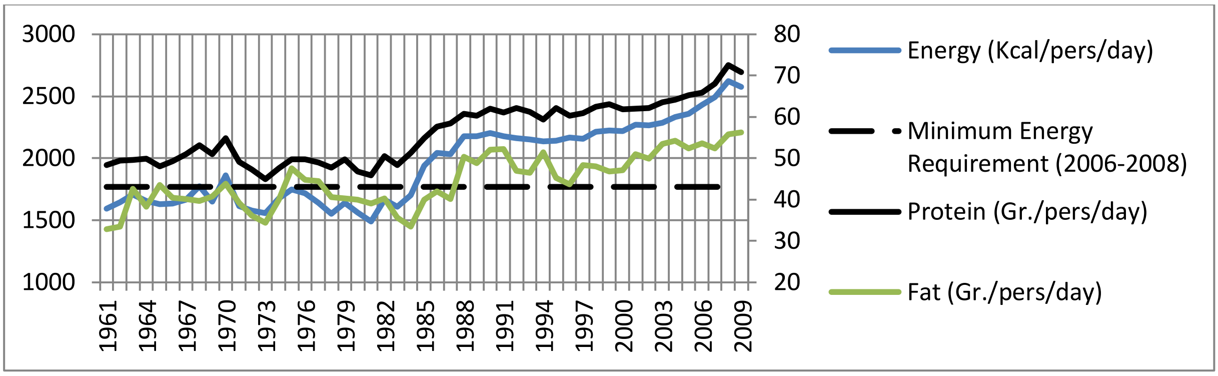


Figure 66: Historical evolution of the total energy, protein and fat consumption in Mali, FAOstat

Figure 67 and Figure 68 show the evolution of the diet regime of the Malian population for the main food commodities and their contribution to the total energy consumption. We can then observe the increased contribution of rice and maize competing against Millet and Sorghum in the Malian diet regime. To conclude, the progressivity of the different factors depends on the evolution of the socio economic context which remains unknown. The constraints to apply long term projections of food demand according to population growth and food requirement remain still very hazardous.

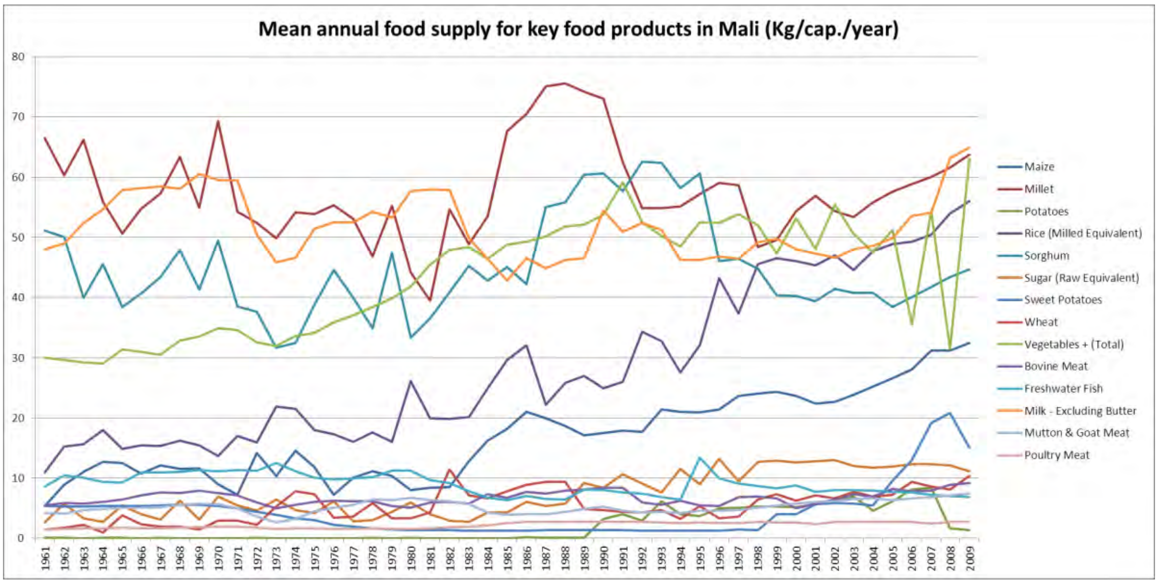


Figure 67: Historical evolution (1961-2009) of the mean annual food supply for the main food commodities in Mali, FAOstat

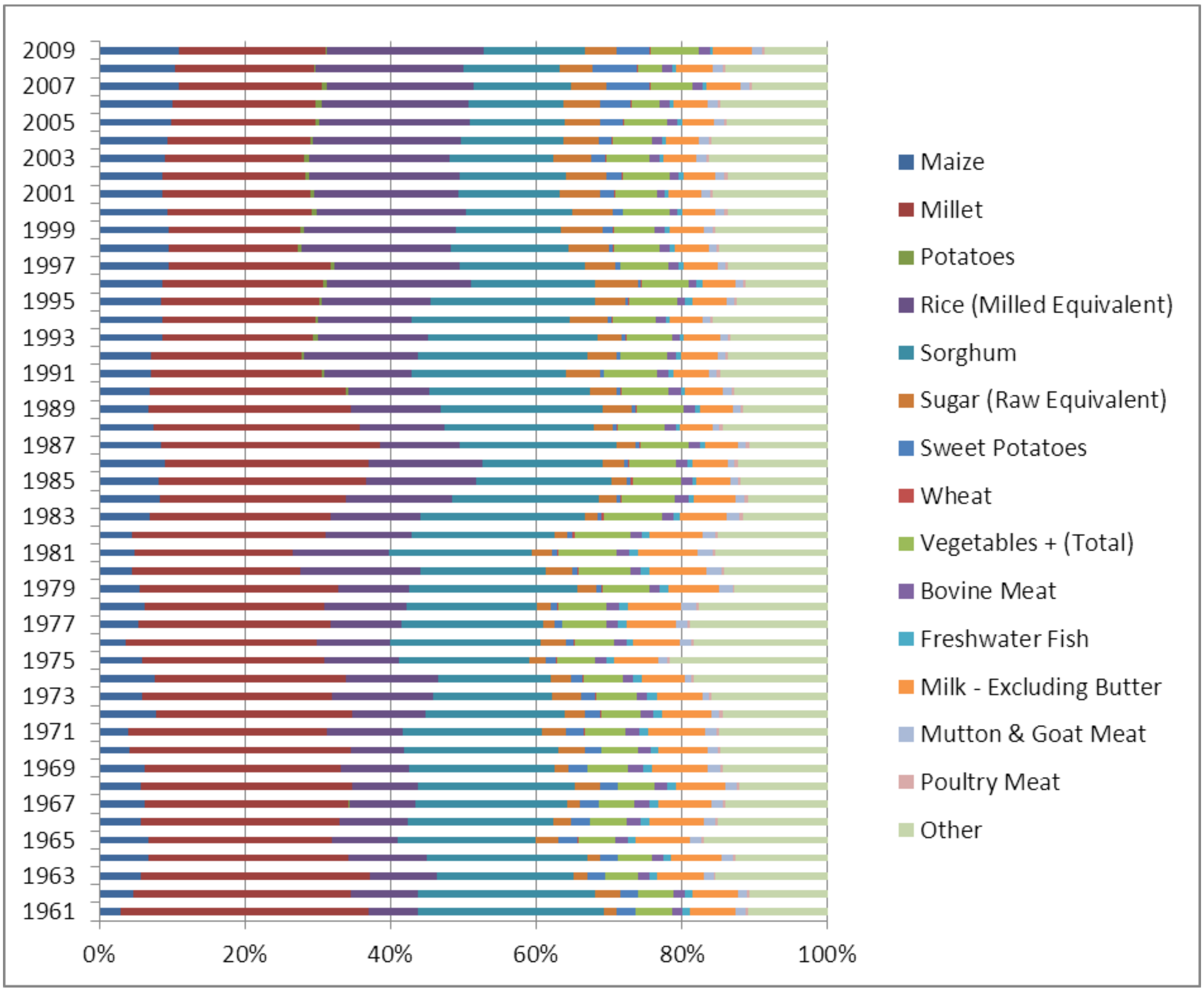


Figure 68: Historical evolution (1961-2009) of the contribution of the main food commodities in the total energy consumption in Mali, FAOstat

4.2.2 Vulnerability and risks at the Niger Basin scale

This sections looks at drought vulnerability at the scale of the entire Niger Basin. The Dewfora Niger Basin case study has mostly focused on the role of drought early warning systems in reducing drought risks for the Upper Niger Basin and especially the Inner Niger Delta. To be able to truly appreciate the results of this case study it is worthwhile to place it in the wider context of the entire Niger Basin scale. This section tries to integrate multiple approaches to drought risks ranging from IWRM, emergency response and conventional livelihood, community development and poverty eradication with experiences from other river basins. It is different from other sections in this report in the sense that it is narrative approach based on expert judgements mostly. Nevertheless, it is assumed that it contains serious concerns and wise lessons that support drought risk management in the Niger basin.

Many definitions for drought exist. In general it can be seen as temporary occurrence and is a direct consequence of a reduction in the amount of precipitation received over an extended period of time, usually a season or more. It results in a water shortage for some activities, groups or environmental sectors (Wilhite and Svoboda, 2000). When departing from different disciplinary perspectives, one often talks about meteorological, agricultural, hydrological and or socio-economic drought. In this section, a holistic approach to drought is taken and hence the socio-economic drought definition, reflecting the relationship between the supply and demand for some commodity or economic good that is dependent on precipitation (UNISDR, 2009) is especially appropriate.

Drought as compared with other natural hazards is often slowly on-setting (and hence can be forecasted relatively well) and may affect large areas and many sectors. A drought may become a disaster when it leads to serious disruption of the functioning of a community or a society that involves widespread human, material, economic or environmental losses and impacts, which exceeds the ability of the affected community or society to cope, using its own resources (UNISDR 2009).

Drought vulnerability refers to the characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a drought. Drought vulnerability can be assessed at individual level (where gender plays a role), community level (where different livelihood activities are essential) or even larger scales. Here, we try to describe drought vulnerability at river basin scale. Below a number of issues are addressed that all are thought to form critical factors in the Niger Basin's drought vulnerability.

Drought is different from aridity or water scarcity, which are semi-permanent conditions. At the basin scale a 2025 projected annual water availability of more than 4,000 per capita indicates that the Niger Basin still provides sufficient water (UNEP, 2008). However both aridity and water scarcity prevail in many parts of the Niger Basin. This results in situations where the effects of droughts are exacerbated by the already on-going water shortages. However, prevailed water shortages over time may also have adapted the society which may have made them resilient in dealing with droughts.

One of the dynamics affecting the Niger Basin's drought vulnerability is the high population growth. This growth is currently 3% (UNDP, 2002). Consequences of this growth increased demands for water, energy and food. In a semi-closed basin like the Niger Basin this requires an optimization of the use of water resources. Drought risk may simply increase by the simple fact of more people being exposed to drought hazards in future. The fast population growth also results in a relatively young population with limited societal memory of earlier droughts. With large percentages of the population living below poverty line (38.4% in Côte d'Ivoire, 46.4% in Burkina Faso, 50% in Cameroon, 60% in Chad, 63% in Niger, NBA (2007)) tend not to help to build drought resilience on community levels (Ward et al., 2009). Often in such cases, people lack resources and time to seriously reduce their drought risks.

The economies of the countries in Niger basin are predominantly natural resource based including mining of natural resources like ores and oil and gas, hydropower but especially agriculture. Agriculture (including livestock rearing contributes to around 40% of the GDP, provides 70 to 80% of the export revenues and involves 80 to 90% of its active population in the Niger Basin (NBA, 2007). Large part of the agricultural economy in the Niger basin countries is subsistence-oriented and mostly rain-fed or flooding-fed based. Only 54,000 hectares of land in the Niger River Basin are irrigated, although the potential is 222,000 hectares, according to the Food and Agriculture Organisation (FAO).The relatively insecured water supply for agricultural production and the large number of people depending on it makes this sector highly vulnerable to droughts in the Niger Basin.

Hydropower dams in the Niger Basin often have multiple functions of creating water storage for power generation and irrigation diversions. Dams design and operations normally have included the effects of a drought and hence its occurrence does not necessarily need to jeopardize hydropower generation of irrigated agricultural production. However, multiple drought years will certainly affect reservoir levels and hence reservoir efficiency. Moreover, political priorities of dam operations towards hydropower generation or irrigation may lead to exacerbation of downstream drought effects such as taking place in the Inner Niger Delta (Zwarts et al., 2005).

The Niger Basin is endowed with high biodiversity areas of which some are protected under nature conservation regimes and conventions like Ramsar Site Designations. It is observed that in case of agricultural droughts, farmers may diversify to fishing livelihoods increasing the pressure on fish-stock exploitation. This may lead to over-exploitation especially when the drought conditions (expressed lower water levels or reduced flood extents) have diminished fish population growth in preceding years. Besides opportunistic livelihood diversification to fisheries, in some parts of the Niger Basin people cope with drought-related food insecurity by means of water bird hunting for subsistence or food supplies to cities. Such exploitation of fish and water birds may lead to significant disturbances in biodiversity values.

One needs to clearly distinguish between drought occurrence in the dryland areas and in the areas in the vicinity of the Niger water bodies. Droughts in the dryland areas where livestock raisings livelihoods prevail leads to migration of the pastoralists and their cattle towards the Niger River itself. This may lead to overexploitation of the river resources such as water and pastures. Conflicts do arise between different livelihoods groups over access and control to the land and water and over land crossing locations and timings. The tribal context of the societies in many parts of the Niger basin area does increase the potential of these drought related conflicts. In case of endured drought or multiple drought years, a rural to urban migration may be observed. Such migration causes effects in two ways: within rural societies the ability to develop collective resilience towards droughts reduces while within cities, demand for food, water and settlements by the newcomers is increased.

Taking the Niger basin scale possible transboundary drought effects need to be addressed. It has secondary and tertiary effects. First, with the water towers of the Niger Basin situated in the mountainous areas of especially Guinea and Southern Mali, reduced rainfall in these areas will eventually lead to hydrological droughts in large parts of the downstream Niger Basin. E.g., reduced rainfall in Guinea may eventually lead to seawater intrusion in the Niger Delta affecting livelihood options and the delta's ecosystems integrity locally. Secondly, drought-related migration does not only take place within nations but may easily occur in a cross-boundary fashion. The third type of transboundary drought consequence may arise when upstream countries develop interventions to combat drought in their countries that may have downstream and transboundary effects (such as the development of water storage). Obviously the Niger basin Authority is the coordinating organ to address this latter issue and to develop coordination across states.

A final issue to be addressed is the decentralization process that has taken place in many African Countries. Based in structural adjustment plans many countries have devolved governmental tasks to lower scale governmental entities including those activities that relate to disaster risks reduction and integrated natural resources management. However and unfortunately in most countries thus decentralization process is far from complete. Local and province scale entities lack the capacity and resources to perform the mandate given to them. Moreover in some cases devolved mandates are not formalized in new water legislation and policies. It is especially at this issue where the FP7 project Afromaison is concentrating on (www.afromaison.org). It tries to improve the INRM capacity on the so-called meso-scale in African countries. With capacities still missing on that scale, top-down approaches to drought risk management and bottom up approaches by developing community-based resilience only meet then sub-optimally.

4.3 PREPAREDNESS

4.3.1 Inventory Mid-term Mitigation Practices, Long-Term Adaptation strategies in the Upper Niger Basin and the Inner Niger Delta

In this section, we aim to present adaptation strategies to climate change in the Inner Niger Delta and socio-economic conditions of their sustainability by sectors. For each sectors, strategies adapted by stakeholders to climate change can be divided into two main groups: local and introduced/improved practices. The review of the adaptation strategies comes from a deep work initiated and finalized with stakeholders during a combined AFROMAISON and DEWFORA workshop (Wetlands International, 2012), field expertise from Wetlands International and a large literature review (Barbier et al., 2008, 2009; Bernus, 1995, Cotula et al., 2006; Downing et al., 1997; Djoudi et al., 2012; Goulden et al. 2011; Maire et al., 2007; Moorehead, 1997; Naess et al., 2010, PDD-DIN, 2011, Quensiere et al., 1994, …) already presented more in details in WP5-D5.4.

(a) **Agriculture**

Farmer strategies/local practices

- Deepening of ponds, canals and supply channels of irrigated areas;
- Displacement of culture in low-lying areas;
- Crop diversification;
- Widespread use of organic fertilizer;
- Adoption of water conservation techniques (zai, micro basins etc.).
- Use of short cycle varieties (e.g. the lowland rice)
- Drought resistant crops and cultures substitution (dry rice) and quick-maturing seed varieties (sorghum and chickpeas)
- Promote 2 to 3 operational crop seasons by supporting a second campaign of rice and gardening and encouraging low-water and off-season farming
-

Solutions and Strategies introduced / improved practices

- Use of early maturing varieties of sorghum, millet, rice provided by the research;
- Irrigation schemes: Several types of structures to retain water in different rice and pastoral records. These are small-scale water storage dams and dikes, small irrigated village perimeters and vegetable gardens.
- Develop Pump-assisted total-water-management irrigation by facilitating motor pump rental or purchase
- Improve the drainage systems in controlled irrigation schemes and prevent salinization with water flushing
- Apply resilient soil conservation techniques that improve soil fertilization and encourage the dissemination of adaptive techniques by training their peers
- Adoption and widespread use of measures of protection and restoration (dikes erosion control, intercropping, soil and water conservation (zai, micro basins);
- Regular supply of fertilizers;
- Development of cropping calendars in different cultures through the support of research;
- Creation of community-managed grain banks where residents have access to additional stores of staple crops, reducing food insecurity
- Creation of a community-managed bank of agricultural inputs and seeds, so that fertilizers are easily accessible, and farmer can increase yields
- Establishment of various producer organizations;
- Improve access to micro-credit to invest in seeds, farming tools, fertilizers
- Arrival of decentralized financial systems.

(b) **Livestock**

Herder strategies/local practices

- Collection and storage bourgou, crop residues, fruits of Acacia albida and Acacia nilotica;
- Organization of communities of farmers and herders for a rational use of the landscape during the farming period.

Solutions and Strategies introduced / improved practices

- Introduction of forage crops (cowpea fodder);
- Create community-managed hayloft to store fodder for the dry season and store “seed” to replant bourgou;
- Intensification of cultivation Echinochloa stagnina (bourgou)
- Training livestock producers on techniques for enriching the rice straw with urea;
- Regular supply of cattle feed (ABH) and animal health protection;
- Development of pastoral wells;
- Organization of breeders for the rational use of pastoral areas;
    - Harmonize the organization and the regulations between the different trails and shelters; Materializing of pastoral areas, crossing points;
    - Reorganize rules to access bourgou pastureland to emphasize access to small and more vulnerable owners (limit monetarization transaction, establish degressive cost for owners of small herd)

(c) Fishing

Fisher strategies/local practices

- Diversification of gear and fishing practices;
- The search for new techniques adapted to the rejuvenation of fish stocks and the exploitation of new habitats;
- Individualized fishing practices
- Changes in the fish processing taking into account the internal and external demand (smoking and burning fish (85%) in favor of drying (15%);
- Extra deltaic migration in search of more productive fishing areas (Sélingué Manatali, Republic of Cote d’Ivoire ...).
- The conversion of fishing to other activities (agriculture, poultry, vegetables, river transport);

Solutions and Strategies introduced / improved practices

- Construction of ponds (fish farming);
- Improved processing techniques / conservation (improved oven: cherkor, insecticides products for the preventive treatment of fish through Operation Fishing Mopti);
    - Promote more efficient collect and storage techniques (to reduce losses after catching)
    - Improve technics and equipment to smoke and dry fish
    - Improve fish transport logistics and equipment from harbor to market place
- Support for the organization of fishermen:
    - Erection fishing councils and development of local fishery conventions;
    - Collective agreements on regulations of fish practices: materials allowed, mesh width, regulation for the use of lateral channels for fish catching or for bourgou fencing
    - Collective agreements to limit fishing zones and forbid access to some areas to maintain the regeneration of the fish population
    - Encourage collective investments and repairment of materials
    - Encourage the development of collective equipment and infrastructures: boat, nets, harbor, market place, smoked and dry fish equipment

- Introduce fishing licence with a mandatory registration to cooperatives
- Introduce fish warden and fine systems that ensure restricted access of fishing zone and the control of regulatory fish practices

(d) Agroforestry and biodiversity

Stakeholder solutions/local practices

- Protection of local tree species;
- Production plants by the village nurseries;
- Use of rural plantations, the hedges, the wind breezes;
- Establishment of village brigades for the protection of fauna and flora
- Valorization of forest products by marketing deadwood

Solutions and Strategies introduced / improved practices

- Introduction of agro forestry;
- Fixing the banks and sand dunes;
- Protection of natural regeneration in certain forest tree planting
- Restoration of flooded and dryland forests on the plains surrounding the delta with the development of local reafforestation and agroforestal conventions
- Apply resilient soil conservation techniques that improve dune fixation and natural regeneration with the encouragement to further disseminate adaptive techniques by training their peers
- Biorights: protection of key biodiversity involving local communities supported by international community
- Encouraging the emergence of alternative solutions and activities to prevent wood overexploitation: other energy access (solar panel and electricity and cooker) if a program of tree plantation is followed by the community.
- Encouraging the emergence of alternative solutions and activities to prevent bird hunting: ecotourism when applied in a good way may offer alternative income but safety, facilities and a good organisation are essential for success, combination may be sought with other localities in Mali.

(e) Provincial spatial planning and land tenure

- Spatial planning master plan for natural resources management at the commune and the Inner Niger Delta scales with stakeholders representatives from all the communities and sectorial activities.
- Clarify legal pluralism between customary and legal land tenure rights and regulations
- Decentralization and local empowerment

4.3.2 Inventory Mid-term Mitigation Practices, Long-Term Adaptation strategies Niger Basin scale

This chapter ends with reflective and discursive thought on how to improve mid-term mitigation practices and long-term adaptation strategies at the scale of the entire Niger Basin. This section is not to be meant conclusive. It only contains concerns and issues based on wider drought management experiences across the world.

Droughts are multi-faceted and complex phenomena taking place on various scales and affecting so many different groups. It is not a surprise that it can be addressed from so many different angles. Within the IWRM sector, drought would be framed as a result of suboptimal water resources management. In organisations responsible for poverty eradication and community and rural development droughts are those shocks jeopardizing sustainable livelihood development. Within the sector dealing with humanitarian crises, droughts are seen as disasters that lead to famine, casualties and migration streams which need emergency response. Governments might frame droughts as constraints to their economic development. Droughts could be related to food security, water scarcity and desertification or the reason for conflicts and a threat to regional human security as researched by Goulden and Few (2011)

People's capacity to develop solutions to drought risks often starts with how droughts are being framed. Different drought framings will appeal to different groups or sectors as it relates to the mind frames, jargon, theories of change and modalities of working commonly applied in those groups working at the Niger Basin Scale. The point is that all those framings are correct and complimentary (and partly overlapping). Complex issues tend to require complex solutions. Solutions based on only one single drought framing might lose out other opportunities. Dealing with drought in the Niger Basin is ideally based on a total of these various ways of working which needs multi-level governance (Pahl-Wost, 2009).

Organisation like the Observatoire du Sahel et du Sahara (OSS); Réseau d'Observatoires de Surveillance Écologique à Long Terme (ROSELT); Comité permanent Inter-Etats de Lutte contre la Sécheresse dans le Sahel (CILLS), Centre Regional Agrhymet (CRA), ACMAD (Weather and Climate Centre with African continental competence); FEWS NET (Famine Early Warning Systems Network), the GIEWS/SMIAR (FAO Global Information and Early Warning System on Food and Agriculture), the WFP (United Nations World Food Programme), the OCHA (Office for the Coordination of Humanitarian Affairs), HIC (Humanitarian Information Centres), the ECHO (European Community Humanitarian Office), the RELIEFWEB (United Nations website providing information to humanitarian relief organizations) which are all grouped into the RCPA (Food crisis prevention network), The Niger Basin Authority, the national governments (central and decentralized departments), research institutes, NGOs and civil based organisation such as water resources user associations, cooperative structures and community groups all play a role in this multi-level and multiple intervention approach to droughts. Sharing of experiences and approaches and pooling of resources and cooperation across these groups and across borders is important. So is coordination of the multiple intervention approaches. For the latter, a Niger Basin wide authority like the Niger Basin Authority supported by other specialized institutions (AGRHYMET, FEWS-NET and ACMAD) is best equipped to perform that task in collaboration with decentralized technical services from ministries of the member countries.

Taking a disaster risk reduction approach (with various phases in the drought risk management cycle of mitigation, preparedness, response and recovery) following basin-scale interventions are thought to be useful at the Niger Basin Scale

Competences for monitoring

- **Climate and Hydrological monitoring:** improving and extending coverage of climate-and hydrological gauge stations and quality check measurements
- **Remote sensing and mapping:** associate the use of satellite imagery to cross validate agricultural sector monitoring and hydrological forecasting tool for the Inner Niger Delta flood propagation. Another use of satellite imageries is the mapping of the spatial and cyclic distribution of natural resources (rice fields, pastureland, dry and flooded forests, submerged areas) which can support the sustainable management and the exploitation of the resources in the IND. Efforts on restoration, protection and development can be also monitored and used in evaluation process with local communities to make transparent what large scale developments may mean in the end for the environment and natural resources on a mesolevel.
- **Capacity building** through provincial staff training in climatology, seasonal forecasting, and agrometeorology. Regional institutions could play a large role to diffuse and harmonize early warning qualifications.

- **Food security monitoring:** definition of a clear method to identify mid-term dry episods and emerging crisis with tailored indicators assessing the current regional food reserves, the seasonal yield conditions, the forecast (combining meteorological and hydrological information) and the food prices status. Identification of different level of emergency plans according to the severity of the situation.

Contingency plans

- **Increase dialogue and cooperation** between international donors, NGO´s and aid agencies with the Malian interministerial committee dealing with severe drought episods and food crisis.
- **Extend the prerogatives of SAP in Mali** to coordinate the aid and the logistics of national and provincial authorities with international aid agencies and NGO´s.
- **Maintaining strategic reserves** allows the government (or marketing bodies) to dampen price fluctuations and release food in emerging crises. Quite large national reserves have been held in the past few decades, in some countries enough food to meet consumption for a year or more. In the 1990s, these reserves were reduced under structural adjustment agreements. International lending organizations noted that such reserves are costly to maintain and absorb a significant fraction of government resources. Better monitoring and timelier responses were seen as more efficient ways to cope with food shortages. Nevertheless, in the context of the Inner Niger Delta with a large interannual and seasonal variability in rainfall and flood volume, the creation of community-managed grain bank where residents have access to additional stores of staple crops, reducing food insecurity seems to be an appropriate answers to extreme drought cycle. In case of food shortage, the infrastructure to store food reserves is already in place and maintained at the community levels. This policy requires a better mediation between governmental services and the interministerial committee with international humanitarian organizations and NGO´s to operate and collaborate efficiently during disaster years with local communities.

Mitigation

- With smallholder farming being a major sector with high drought vulnerability, facilitating the **improvement of food and water productivity (**irrigation techniques, mulching, less water demanding crops, drought-resistant crops, reduce losses of food and water) contributes to community-scale drought resilience. Though such interventions are implemented by individual farmers at plot scales, governments and basin-wide organization are essential in creating the enabling environment (awareness raising, capacity building, subsidies, etc.).
- With the Niger Basin being relatively untapped (Hassane et al., 2002) and a predominantly rain-fed based agriculture, increasing the Niger Basin food security by means of **developing irrigated agriculture** seems a logical step. This irrigation potential can be developed at large scale possible needing management by governmentally based entities or at grass-root level with community-based management. In the latter case, governments again need to create the enabling environment that allows embedding these community-based management structures in the wider governance landscape. Increased irrigation needs water infrastructure like water diversions and storage reservoirs. Developing such infrastructure needs to be carried out in a participatory and information based approach in order to avoid unintended socio-economic and environmental consequences and upstream-downstream conflicts. The use of natural engineered solutions (Burek et al. 2012) is increasingly being considered to deal with European droughts (and floods). The potential to use the Niger Basin's subsurface groundwater reservoirs for further water development needs further exploration

- Community-based resilience to disasters like droughts can be created by **diversification of livelihoods**. This is often an autonomous process already practiced by many individual farmers, fishermen and pastoralists (Zwarts, 2005). This diversification could be further enhanced with governmental and NGO-based support which focusses on more profitable agriculture with mechanization and value adding processes like processing, transportation, and storage and access to local and international market.

Preparedness

- **Drought vulnerability assessments** need to be carried **at various scales** (community, national and international; sub-catchment, catchment and entire river basin; within sectors and cross-sectorial). Such assessment should lead to Drought Risk Reduction Plan. Organisational entities at larger scales should provide the enabling environment for entities at lower scales to be able to perform their tasks. Traditional adaptive measures need to be learned from and included in the plans. Drought risk assessment and management plans should correlate to wider disaster reduction plans and include climate change effects. Drought vulnerability assessments could be linked to Strategic Environmental Assessments (SEA) and food water energy ecosystems nexus assessments. The potential of Eco-system based approaches to disaster reduction could be further explored.
- **Drought early warning systems** are of paramount importance for preparedness. DEWFORA is dedicated to this part of the preparedness. Again DEWS should be made fit to the scale of use and fit in the mind frames of the beneficiaries. A DEWS tool with marvellous forecasting skills but with information that is not accessible to and understandable by the users for which it is intended to does not have an added value.
- **Drought risk reduction** and the wider disaster risk reduction needs to be mainstreamed in various national and basin-wide policies and initiatives that address water, food, energy, human and environmental securities, poverty reduction rural and spatial development and trade developments.

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