Constraints of future freshwater resources in the Upper Niger Basin – Has the human-environmental system of the Inner Niger Delta a chance to survive?

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Abstract: The Inner Niger Delta in the West African Sahel is one of the largest wetlands in the world. Growing populations and developing living standards in the Upper Niger Basin are increasing the needs for food and energy and put enormous pressure on limited natural resources. The extension of irrigated agricultural areas and the construction of new dams and reservoirs to store and distribute water and to generate hydropower seem to be necessary strategies to satisfy the increasing demands. As a consequence, the natural water regime of the River Niger is modified and will be subject to further regulation with largely negative effects for the Inner Niger Delta in Mali. Climate projections, used in this study, in combination with reservoir control lead to a significant reduction of peak discharges and are thus a large threat for the wetland’s ecosystem functions. Hydropower generation requires water during the dry season and consequently, the low flows are considerably increased due to dam management. The latter has certainly positive effects on water quality and thus on human health, but might also have negative impacts on the IND ecosystem that is accustomed to or even requires extremely dry and wet conditions to maintain its integrity. The impacts of climate change and reservoir control strategies on wetland inflows and inundation patterns as well as mitigation options are investigated in this study by analysing various water management and regionalised climate scenarios. The usage of “excess” water due to increased discharges in the dry season for irrigation could be such a mitigation strategy. A process-based eco-hydrological modelling system equipped with an inundation module and a reservoir module was used for this purpose.

Keywords: Inner Niger Delta; Water resources management; Climate impacts; West Africa; Hydrological modelling

1 INTRODUCTION

Humankind is shaping its environment for its own purpose, sometimes in a sustainable way but most of the time driven by short-term thinking and therefore in an unsustainable manner. Scenario analysis has the potential to reveal the consequences of human actions or inactions under changing boundary conditions such as climate change. They are suitable tools to anticipate change and to develop strategies to adapt to changing conditions and to assess the impacts of reactive or proactive behaviour. The extent,
to which scenarios are useful for planning purposes is determined by their underlying assumptions, the time period considered, and the way how adaptive measures are implemented. While it is technically rather “easy” to assess the impacts of climate change on water availability over the next 50 years (neglecting the oftentimes opposing assertions of climate models), it is rather difficult to anticipate the way how societies will adapt to changing conditions during the scenario period (technical solutions, migration etc.). To account for and to implement the dynamic nature of adaptation in scenarios is challenging. However, dynamic adaptation strategies are not implemented in this study, it rather employs scenarios to emphasise the point in time when the need for adaptation becomes urgent. This manuscript investigates the impacts of climate change and upstream water management on ecosystem functions of the Inner Niger Delta (IND) and the carrying capacity of the IND in terms of food production for the human population.

There is a strong functional relationship between flooding patterns and food production in the IND, as described by Zwarts et al. [2005]. In general the assumption holds that the larger the inundated area, the more benefits for livelihoods and for ecosystem integrity are gained. Hence, all factors that influence the inflow patterns into the IND have an impact on food production and ecological conditions in the wetland area.

Liersch et al. [2012] investigated the impacts of climate change and upstream water management on food production in the IND under two population growth scenarios. In this study, the focus is on the assessment of external impacts on the carrying capacity of the IND with regard to the number of people that can be supported by the ecosystem service related to rice production.

2 Study Area

The IND is a vast riverine floodplain in the semi-arid to arid Sahelian zone in Mali that supports livelihoods in fishing, farming, and stock farming [Zwarts et al., 2006] for currently 1.5 million people. It is located in the Upper Niger catchment that covers an area of 350,000 km² (Figure 1). The catchment is subject to enormous seasonal and interannual variation in rainfall and river flow [Zwarts et al., 2006] and rainfall is very unequally distributed in the Upper Niger Basin. The headwater regions receive up to 2,000 mm of rainfall during the rainy season (July to October), the IND only 200 to 500 mm. The water balance of the IND is always negative due to high evapotranspiration rates. The wetland is mainly fed by the Rivers Niger and Bani. During and after the rainy season, large areas are inundated. In the wet 1950’s and 1960’s, the total flooded surface area was up to 40,000 km². However, due to climate change or variability, the 1970’s and 1980’s were very dry and although the climate conditions during the last 20 years were comparably wetter, the total flooded surface area did not exceed 21,000 km² [Mahé et al., 2011].

The agricultural system in the IND is very complex and the multiple usage of natural resources is based on community rules and customs that have shaped the way in which societies have administrated this area for a long time [Marie et al., 2007]. Bourgou pastures serve as very nutritious floating grass for livestock, as nursery for fish, and are important habitats for waterbirds. The main staple crop is rice, mainly floating rice (Oryza glaberrima), that is traditionally produced by either controlled submersion or natural flooding. The third main food source is fish. The population in the IND make their living usually from subsistence farming.
3 METHODS

3.1 SWIM

The eco-hydrological model SWIM (Soil and Water Integrated Model, [Krysanova et al., 2005]) was used to simulate the impacts of climate change and upstream water management scenarios on discharges into the IND and wetland inundation. SWIM is a continuous-time spatially semi-distributed process-based hydrological model. It integrates physics-based and conceptual approaches to simulate hydrological process, vegetation growth, nutrient cycling, and sediment transport. A reservoir module [Koch et al., 2011] was implemented in order to assess the impacts of reservoir management (maximise hydropower, regulation on downstream demands) on river runoff and to estimate hydropower generation. Flooding and release processes and evapotranspiration in the wetland simulates an inundation module integrated into SWIM.

3.2 Scenarios

Impacts of climate change on river runoff and inundation were investigated by using two regional climate models (STAR and REMO). The statistical regional climate model STAR [Orlowsky et al., 2008] was used to project future climate for the period 2011-2050 based on the WATCH [Weedon et al., 2011] climate dataset of the period 1960-2001. Three temperature driven scenarios each with 100 realisations were developed. The first scenario was used to project the conditions at the end of the 20th century into the future (0°C scenario). The other two scenarios assume temperature increases of 0.75°C and 1.5°C. The observed temperature trend in the WATCH climate time series (1960-2001) was 0.75°C. Whereas rainfall does not change significantly in the 0°C scenario, the other two scenarios are characterised by rather strong decline of rainfall amounts.
REMO [Jacob, 2001; Paeth et al., 2005] is a dynamical regional climate model that was driven by the GCM ECHAM5 [Roeckner et al., 2006]. Three realisations in each case of the SRES A1B and B1 scenarios were used in this study.

In order to analyse the impact of reservoir management on the flow regime and inundation patterns in the IND, the existing Sélingué dam in Mali, built in 1982, and the planned Fomi dam in Guinea were implemented in the model SWIM.

3.3 Indicators

Basically two indicators total flooded surface area and usable area for rice production were used to determine the impact of changing boundary conditions. Total flooded surface area is used as a surrogate for ecological integrity. The larger the flooded surface area, the better are the ecological conditions for various aspects, such as flood forests, bourgou pastures, and other important habitats. Usable areas for rice production are areas that are inundated for at least 90 days by water levels between 1-2 metres. This indicator is used to assess the carrying capacity of the IND to support the local human population with respect to rice production.

4 RESULTS

4.1 Impacts on River Runoff

Figure 2 shows the impact of climate scenarios and reservoir management on runoff at gauge Koulikoro (see Figure 1). The flood peak is a first indicator for the extent of wetland inundation. The impact of climate change for the period 2031-2050 on runoff, as projected by the REMO model, (see Figure 2 a), is more or less in the range of the 100 realisations of the STAR 0°C scenario. Neither the A1B nor the B1 scenario has significant impacts on peak flows in August/September. Compared to the REMO reference period, simulated annual runoff is lower mainly during the period September to December.

Figure 2 b) illustrates the impact of climate change and reservoir management on river runoff using STAR climate projections. Observed runoff in the period before the Sélingué dam was built, is used to compare unmanaged and managed runoff (including the existing Sélingué dam and in combination with the planned Fomi dam). The management of an additional reservoir in the Niger headwaters would have impacts on peak flows as well as on low flows. Compared to the current conditions (including the Sélingué dam), the Fomi dam would reduce the peak flows by approximately 550 m$^3$/s in the 0°C scenario and by 300 m$^3$/s in the 1.5°C scenario. There is a significant increase of low flows by 300-350 m$^3$/s. However, low flows do not change significantly across the scenarios.

4.2 Impacts on Ecosystem

Due to the fact that simulated runoff using REMO climate input is comparable to the 0°C scenario of the STAR model, we investigate only the impacts of STAR projections. A consequence of reduced peak flows due to projected climate and reservoir management scenarios is a reduction of the total flooded surface area in the IND. Figure 3 shows the impacts of the scenarios on the total flooded surface area when the simulated flooded surface area falls below or is close to the critical threshold of 5,000 km$^2$. This threshold indicates severe drought years as have occurred in the years 1984 and 2011 (twice in the last three decades or in 6.7% of the years). In the 0°C scenario, such an event is projected to occur in 16.5% of the years under current reservoir management (includ-
Figure 2: Climate change and reservoir impacts on runoff

Increased runoff during the low flow period (due to the simulated management of the Fomi reservoir) has certainly positive effects on water quality and availability in the IND during the dry period but could have negative consequences for the ecosystem that is adapted to extremely dry and extremely wet conditions. Fishermen, for instance, reported losses of fish catch during years with higher low flows than under natural conditions.

4.3 Impacts on Carrying Capacity

Figure 4 illustrates the impact of climate change and reservoir management on the potential rice production in the IND and consequently its carrying capacity to support subsistence farming. In the national plan of Mali [RDM, 2010] it is reported that cereal consumption is about 214 kg/person and year. Rice is the main staple crop in the IND and is therefore used as surrogate for cereal production and provisioning.
The usable areas for floating rice production in the IND were simulated using the inundation module. The product of usable area and the average productivity (2 t rice/ha, an optimistic assumption) determine the production potential within the IND. Figure 4 demonstrates the number of people that can be supported by this ecosystem service, not accounting for adaptive measures, such as increasing the productivity by using different species or changes in the management. The coloured bands show the range between the 33rd and 66th percentiles of the 100 realisations (assuming no upstream reservoirs). The continuous black lines indicate the mean number of people that can be supported by subsistence rice farming assuming the existence of the Sélingué dam (current conditions), and the dashed black lines show the impact of the planned Fomi dam. In the 0°C scenario, the simulated carrying capacity moves around 1.5 million people, the current number of inhabitants. In the 0.75°C scenario, the number drops below 1.0 million and below 0.5 million in the 1.5°C scenario by the end of the simulation period.

5 Conclusions and Recommendations

The 0.75°C and the 1.5°C STAR scenarios project a devastating future for the Inner Niger Delta’s (IND) ecosystem and human population. Peak discharges into the IND, required to inundate temporary wetland areas, decrease substantially due to the dry future (reduction of 10-20% of annual rainfall). These two scenarios reveal some consequences if the region is subject to further drying, which should be considered as one possible future of the region. The probability of the occurrence of drought years, as in 1984 and 2011, is likely to increase substantially from 6.7% (last three decades) to around 60% in the 0.75°C and 80% of the years in the 1.5°C scenario in 2021-2050. Food production in the IND is also adversely effected. Without adaptive measures, the carrying capacity of the region shrinks dramatically. At the end of the simulation period, the number of people who can make their living from subsistence rice farming shrinks from currently 1.5 million to 0.75 million in the 0.75°C and to around 0.5 million people in the 1.5°C scenario. The
construction of an additional reservoir in the Niger headwaters would reduce the carrying capacity of the IND by up to 10% in the 0.75°C and up to 23% in the 1.5°C scenario. However, the A1B and B1 scenarios of the REMO model that are within the range of the 100 realisations of the 0°C scenario of the STAR model, are a bit more encouraging. Although it should be noted that the mean of the 100 realisations is a continuation of the recent climate, the range of the 0°C scenario is rather large, where dry realisations are within the upper range of the 0.75°C scenario. Regarding the occurrence of drought years, the probability increases from currently 6.7% to 16.5% (current upstream reservoir management) and to 23% including the planned Fomi dam in Guinea. The carrying capacity of the IND for subsistence rice farming is in the range of 1.2 to 1.7 million people, considering the 33rd and 66th percentiles of the 100 realisations. Still unclear are the consequences of increased low flows on ecosystem functioning during the dry period.

The answer to the question raised in the title: *Has the human-environmental system of the Inner Niger Delta a chance to survive?* is: “Well, it depends on the scenario we consider!” The human population will adapt to changing conditions anyway, be it by migration to other regions or by inventing new strategies to cope with the challenges. The basic question seems to be whether the ecosystem of the IND has a chance to survive under the increasing pressure of a developing population and other external changes. An important issue in this respect is: “the smaller the wetland, the higher the pressure of the human population to overuse natural resources”, challenging ecosystem functioning.

Issues that were not addressed by this study and should be integrated in further investigations are: 1) to incorporate the development and implications of upstream irrigated areas; 2) to incorporate other planned reservoir projects beside Fomi; 3) to study the impacts of changing boundary conditions on fishery and livestock; 4) include impacts on specific habitats, particularly the impacts of increased low flows; and 5) to account for dynamic adaptation strategies by confronting stakeholders and decision makers with situations of change after a manageable time and to incorporate their reactions in an iterative way to develop dynamic scenarios.
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REFERENCES


