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Regional integrated modelling of climate change impacts on natural resources and resource usage in semi-arid Northeast Brazil

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Abstract

Semi-arid regions are characterised by a high vulnerability of natural resources to climate change, pronounced climatic variability and often by water scarcity and related social stress. The analysis of the dynamics of natural conditions and the assessment of possible strategies to cope with drought-related problems require an integration of diverse knowledge including climatology, hydrology, and socio-economics. The integrated model introduced here dynamically describes the relationships between climate forcing, water availability, agriculture and selected societal processes. The model has been designed to simulate the complex human-environment system in semi-arid Northeast Brazil quantitatively and is applied to study the sensitivity of regional natural resources and socio-economy to climate change. The validity of the model is considered.

Climate change is concluded to have an enormous potential impact on the region. River flow, water storage and irrigated production are specifically affected, assuming a continuous regional development and unfavourable but plausible changes in climate. Under plausible favourable changes in climate, these variables remain stressed. The impact of the integrated model and its applications on present policy making and possible future roles are briefly discussed.

Keywords: Integrated modelling; Climate change; Regional modelling; Drought; Policy support

1. Introduction

Societies in semi-arid areas in developing regions are specifically vulnerable to variability of climate and water availability and therefore potentially vulnerable to changes of climate conditions. This vulnerability is caused by the strong restrictions on the use of natural resources by the limitations in water availability that already occurs under average conditions, the generally low consistency of water availability and, on the other hand, a still high density of population, strongly depending on these resources with little short-term options to reduce the dependency. Reasonable conditions in wetter years support the persistence of population in the area; marginal or poor conditions in drier years and development arrears hamper significant improvements in the quality of life.

Clearly, the study of global change impacts in developing semi-arid regions calls for an integrated approach. Climate impacts are not only an effect of changes in water availability, but emerge from the confrontation of availability and societal demands and the role these demands play in society. Therefore, an appropriate integrated study should include both the physical understanding of climate effects on the water balance and on crop yields, and an analysis of water use, agricultural economy and societal impacts. In Northeast Brazil, one of the most marked societal impacts of droughts is the emigration of population from rural areas to the urban centres and to destinations outside the region (Gaiser et al., 2003b).

It is the goal of environmental management in semi-arid regions to reduce vulnerability against water stress and droughts and to enhance the resilience of the human-environmental

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system. At a longer time perspective (over generations) this can only be achieved by aiming for a sustainable use of water and land resources, which must be an integrating process, encompassing climate, natural resources (water, soil), technology, ecology, economy, and the society (Loucks, 2000). Regional integrated modelling can supply both a conceptual framework and an application tool for integration of such different scientific disciplines.

This paper presents an integrated assessment of regional climate change impacts on natural resources and their usage, based on integrated modelling. The model describes the basic dependencies in the human-environment system. The role of this knowledge in the regional policy making process and the appropriateness of the approach used are briefly discussed.

2. Regional integrated modelling

The research area of integrated modelling in the context of climate and environmental change studies is developing rapidly, see e.g. Bronstert et al. (2004). Early integrated models emerged merely as extensions of natural science or macro-economic models, adopting additional dynamic descriptions of driving factors or impacts. Afterwards, integrated models appeared from intrinsically integrated problem analyses. The relevance of regional factors in global warming impacts on regional resources and socio-economy is increasingly recognised, considering not only realisations of climate change within the regional climate systems but also accounting for regional characteristics like soil, vegetation, rivers and water management systems. These factors represent the exposure of regional resources by climate change and the sensitivity of resources and socio-economy to climate and environmental change. Next to these, the regional adaptive capacity, depending on geo-biophysical as well as socio-economic conditions, is a key factor in the vulnerability of a region to climate change, leading to very regionally specific main concerns with respect to climate and environmental change (McCarthy et al., 2001). Developing regions tend to have a smaller adaptive capacity and thus be more vulnerable to such changes than developed ones. The integrative understanding of the natural-social-economic system, however, is not advanced enough to come to firm conclusions on consequences of environmental change and on appropriate mitigation strategies. For instance, knowledge on adaptability relate to climate and hydrologic variability rather than to climate change, where the transferability of findings is an open issue (McCarthy et al., 2001). Such considerations underline the urge for integrative regional studies. For water-related issues, this urge connects to the international policy rulings and recommendations for integrated water resources management at the catchment scale, as reflected in, e.g., the Water Framework Directive of the European Union (European Commission, 2002) or by the World Water Forum 3 (2003). Nevertheless, modelling at the global or continental scale (e.g., Vörösmarty et al., 2000; Lehner et al., 2001; Döll et al., 2003; Bronstert et al., 2004) is required as well to identify present and future water-related problems and their world-wide significance, and to represent the feedback of changes in the terrestrial water cycle to the global biogeochemical cycle.

Regional impact assessments need to establish the links between different scientific disciplines and to integrate the various discipline-specific methodological approaches. In the past decade a number of regional integrated impact studies have been conducted in different regions of the globe. In a study of the McKenzie basin in Canada (Cohen, 1997), climate and hydrology are studied jointly using integrated modelling and stakeholder-specific priorities for climate change-related issues. Turner et al. (2003a,b) use the concept of vulnerability as a central vehicle for integration. In a series of German integrative catchment studies, various conceptual approaches towards integration are attempted: for the upper Danube (Hennicker et al., 2003), a computer-network-based approach is taken to dynamically link disciplinary modules, which are modelled in a distributed way on common process pixels; for the river Elbe, an integrative framework considers the cycle of problem setting, criteria selection, scenario-definition including policy measures, and multi-criteria multi-stakeholder analysis of alternatives, where impacts are estimated using input–output linkages of chains of disciplinary or partly integrated models (Becker et al., 2001); for the river Volta (Van de Giesen et al., 2001), three clusters of integrated dynamic models are defined, with different levels of manageability (atmosphere, land use, water use), connected through interfaces, where physical models and agent-based approaches are included within the clusters.

Various projects aiming at constructing Decision-Support Systems (DSSs) similarly consider water issues in specific water- or land use-related policy field. They often combine dynamic modelling approach at the aggregated scale with pre-processed spatial representations or spatial dynamic approaches for smaller scale effects (Bathurst et al., 2003; Engelen et al., 2003; De Kok and Wind, 2003), avoiding the computational burden of small scale temporally and spatially dynamic models.

The main difference of DSSs in comparison to IAMs lies in their aim, to not only generate information relevant for policy making, but also to explicitly organise the access to the information for policy makers in a software tool and to explicitly support a decision-making process. To this end, DSSs present the effects of possible policy measures and may offer policy maker opportunities to define alternative combinations of policy measures to be analysed on their effects.

3. Case-study for Northeast Brazil

3.1. Study area

Northeast Brazil is seriously influenced by the insufficiency and unreliability of precipitation. Adverse natural conditions, combined with the underdevelopment in the region jointly bring about that the rural population cannot support itself in drought years (Gaiser et al., 2003b). Inside the region lies the so-called *drought polygon*, a semi-arid area of about 940,000 km^2 stretching over nine federal states in Brazil, where droughts occur rather frequently. The study area, consisting of the two Brazilian federal states of Ceará and Piauí, is largely situated inside that drought polygon (Fig. 1), together covering an area of 400,000 km^2.

Most of this area has a semi-arid climate with precipitation ranging from 500 to 900 mm/year whereas potential evapotranspiration exceeds 2000 mm/year.

Precipitation is strongly seasonal and its inter-annual variability is high, related to El Niño, leading to irregularly recurring severe droughts. All important rivers in the region are intermittent. Dam construction, aiming at providing perennial river flow and urban water supply has a tradition of over a century. In rural areas an immense number of small reservoirs succeed to store water to overcome shortage in the dry season of regular years, but fail for multi-year drought periods. Groundwater availability in the crystalline interior is scattered and waters often are saline. Major aquifer systems exist only in the coastal region and the downstream area of the Jaguaribe, the main river of Ceará and the largest river in Brazil for which the complete basin is semi-arid. Both for irrigated agriculture and municipal water supply, water management is vital. For example, during the dry season the water supply of the metropolitan area of Fortaleza, with more than 2 million inhabitants, almost completely relies on long distance water transfer.

Apart from alluvial soils in the river beds, soils are generally shallow and poor. Land use consists largely of extensive cattle holding and subsistence farming, with maize, beans, dry rice, and cassava as main crops. Distribution of land tenure and income is very uneven, leading to a high vulnerability of small subsistence farmers. Current population is about 10 million, increasing at a rate of 1.4% per year. A steady rural–urban migration compensates the rural birth excess, with a strongly elevated migration in drought years. Regional urban centres are the common primary migration destiny; metropolitan areas in Brazil's South or to land reclamation areas in the Amazon area are primary or secondary migration destinations.

Earlier regional studies on Northeast Brazil (UNEP study of climate variability and agriculture in the semi-arid tropics, Magalhães et al., 1988) were broad and rich in information but did not arrive at an integrative concept as adopted here.

Since the late 1980s, Brazil is striving to implement aspects of integrated and participative water management into its policies (ANA, 2002a). To this end, river basin committees were

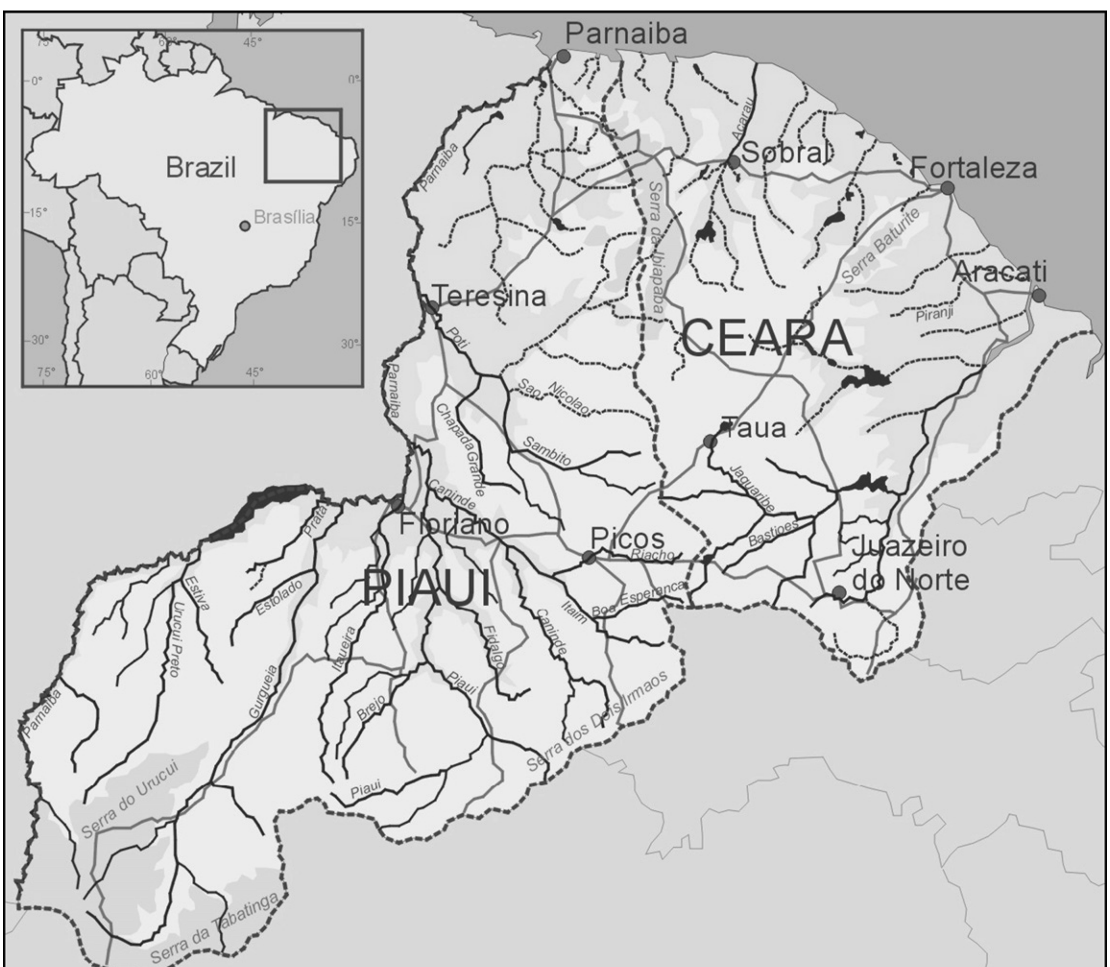

Fig. 1. Study area, consisting of the Brazilian federal states of Ceará and Piauí.

erected in several (sub-)catchments, and co-operations of political and operational units active in land use and water policies were initiated. At present, integrated water resources management is still in its implementation stages. Within the drought-prone areas in Brazil, Ceará is the frontrunners in this process (ANA, 2002b).

Up to the middle of the 1990s, regional water-related policies were oriented towards managing problems related to drought or increasing water demand and to expand irrigation; the issue of climate change was not considered, whereas new water-related policies rely on the construction of infrastructure with life-times comparable to the time scale of climate change.

3.2. Model description

Integrated modelling ideally starts with a clear definition and a systems analysis of the problem studied. The case-study presented below focuses on the assessment of relationships between water availability and quality of life and migration in the rural semi-arid Northeast Brazil at the meso-/macro-scale in the context of global change, especially climate change.

The integrated model constructed focuses on the dominant internal dynamics and on the sensitivity of regional natural resources and socio-economy to climate change. For Northeast Brazil, agriculture was found to be the central connection between the themes water and societal change, agriculture being both the main water user and the main source of labour and income in the interior, and economic prospects being the main driver of migration (Fig. 2). Therefore, descriptive models for water balance, the agricultural sector and migration were required as a central core of the integrated model.

The regional integrated model for the semi-arid Northeast Brazil (Semi-arid Integrated Model, SIM, Bronstert et al., 2000; Krol et al., 2001) is built up in a modular way, roughly representing the disciplinary contributions from different research groups. Each module has discipline-specific methodological characteristics. Modules are linked by an overall framework and all couplings are executed within this framework. This "on-line" coupling mode enables a direct consideration of feedback effects within the integrated model. The code was mainly implemented in FORTRAN, partly in the non-linear optimisation software GAMS (General Algebraic Modeling System, Brooke et al., 1998), and operating under either Windows or UNIX.

SIM covers different space and time scales, ranging from terrain units (average extend: few tens of km^2) to aggregated administrative units (several 1000 km^2), and from days to decades. The modelled region covers the Brazilian Federal States of Ceará and Piauí, an area of almost 400,000 km^2, and the total simulation period is about 20 years for current conditions and 100 years for scenario conditions. The common spatial resolution for all modules (spatial resolution for information exchange between the modules) is the municipality, an administrative unit with in average about 1200 km^2 in size. The common temporal resolution is one year. Module pairs exchange data at their shared resolutions, possibly much finer than the common resolution in SIM. The different scales and resolutions of the individual modules require the application of aggregation procedures such as weighted averaging or dis-aggregation procedures.

Fig. 3 presents a scheme of the coupled modules of SIM, being summarised in the following paragraphs with focus on the water-related components which are of particular interest in this article.

3.2.1. Climate

Climate forcing is input to SIM, where historic data and climate change scenarios are available. The historic

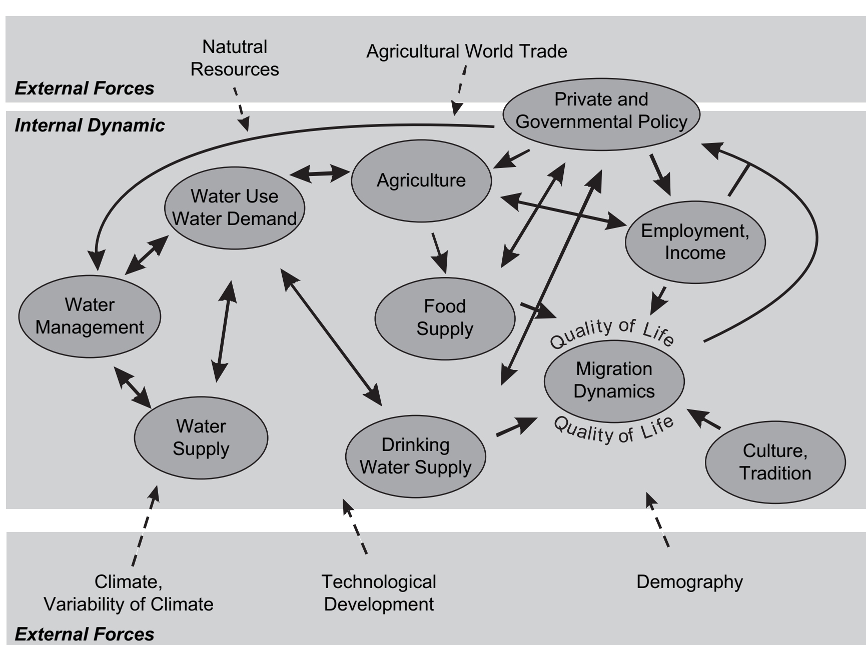

Fig. 2. Conceptual model of dynamic relationships between water availability, agriculture and migration in North-eastern Brazil, as influenced by global change.

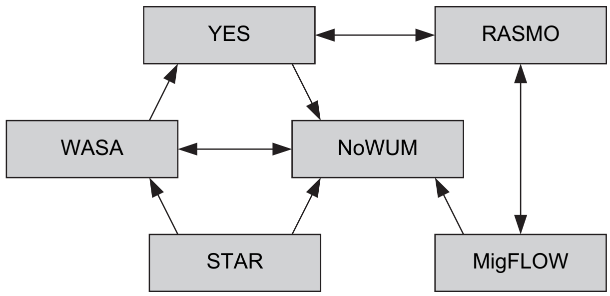

Fig. 3. Modules and their couplings in SIM. Models included are the regional climate scenario generator STAR (Werner and Gerstengarbe, 1997), the regional water balance model WASA (Güntner, 2002), the water sue model NoWUM (Döll and Hauschild, 2002), the agricultural yield model YES (Jaeger, 2003), the regional agricultural economy model RASMO (Höynck, 2003) and the population dynamics model MigFLOW (Fuhr et al., 2003).

reconstruction consists of daily time series of precipitation and temperature at municipal resolution for the period 1921–1998; climate scenarios result from the statistical scenario technique STAR (Werner and Gerstengarbe, 1997).

3.2.2. Water availability

A large-scale water balance model for semi-arid conditions (WASA) describes the soil moisture budget, runoff generation, river discharge, and surface water storage. It accounts for vertical and lateral hydrological processes depending on topography, soil and vegetation cover. Included are evapotranspiration, runoff generation and infiltration, but also lateral processes at the hill-slope scale that usually not perceived in large-scale hydrological models (Güntner and Bronstert, 2004). The modelling units at different spatial scales range from landscape units with similar lateral flow characteristics, aggregated terrain components, soil-vegetation components to representative soil profiles (Güntner, 2002).

Water management in the region largely relies on surface reservoirs, of which over 7000 exist in the region. Large reservoirs (storage capacity $>50 \times 10^6$ m^3) are represented by explicit water balances, small reservoirs are captured by means of their distribution over storage volume classes, that are represented by average characteristics. A simple cascade scheme is routes runoff between reservoir classes and to the river (Güntner et al., 2004).

Model validation showed a fair to good simulation (by the definition Andersen et al., 2001) of monthly and annual flow for discharge stations with a basin area of at least 10^4 km^2, and of annual mean storage volumes in the large reservoirs (Güntner, 2002).

3.2.3. Water use

A water use model (NoWUM) simulates water withdrawal from groundwater, rivers and reservoirs and consumptive water use in all municipalities, considering five water use sectors, i.e., irrigation, livestock, household, industry and tourism (Döll and Hauschild, 2002). Sectoral water use is computed as a function of a sectoral driving force of water use and specific water use intensity; both varying over the simulation period.

Validation of NoWUM is mostly restricted to the general plausibility of the model, obtained from the usage of methods validated under similar conditions and from expert opinion. Geographically explicit regional data are available, but time series are generally lacking, yielding sufficient data for model verification only.

The most relevant link of the water use to the water availability module is performed by a direct coupling of withdrawal and return flow to the reservoirs and rivers. This coupling is implemented at the municipal scale on a daily basis.

3.2.4. Agriculture

Crop yields and production for the regionally most important crops (including maize, bean, rice, cashew) are simulated using a scheme for yield response to water and aeration stress (FAO, 1979), and including soil quality (Gaiser et al., 2003a) and different management methods (Jaeger, 2003). The module (YES) uses evapotranspiration results obtained from the hydrological module. In the model, grassland is treated as a crop; scenario-based animal production is included with direct linkages to feed production, water requirement and economic output.

In a validation of YES, the comparison with crop production statistics at the state resulted in a bias of about 10% and correlations above 6 for the main crops; spatial correlations of temporally average yields at the municipal scale ranged from 0.2 to 0.3 for the main crops and from 0.35 to 0.5 at the scale of meso-regions (magnitude 20,000 km^2).

Agro-economy is represented by an optimisation model for farm income (RASMO), varying cropping and husbandry activities, constrained by available land, technical and financial opportunities, feed and food requirements, and accounting for costs and benefits (Höynck, 2003).

Both irrigated and rain-fed farming are simulated. For scenario simulations, future changes in the area potentially irrigated land are estimated from overall agro-economic projections. The model is strongly calibrated and its results should be considered indicative.

3.2.5. Socio-economy

Migration between municipalities and to external destinies is preliminarily modelled to occur when gradients in the quality of life exceed migration costs in a push–pull model MigFLOW. Here quality of life is a composite indicator, where mean municipal income is the dominant influence (Fuhr et al., 2003; Krol et al., 2004). Migration is consistently accounted for in a demographic model.

The socio-economic model is calibrated for the period 1985–1996. As simulated population migration is less dependent on internal dynamics and more directly on scenario assumptions that should be based on limited data, these simulations are assessed as exploratory.

Validation of an integrated model describing large-scale long-term dynamics is a difficult task. Individual components can be validated in disciplinary tradition. Validation of the described linkages and feedbacks between the disciplinary themes often has to rely on one overall historic reconstruction, a data set which may be incomplete, inhomogeneous and including appreciable uncertainty. The validation of the integration of the modules may therefore be rather limited. Best options for validation are often offered by considering the performance at a sub-regional scale, when regional scale data are already used for calibration, or specific model output variables that were not considered in calibration processes.

For SIM, the validation of the simulation of water balance and agricultural production at various scales did involve comparisons over periods where the coupling of climate, hydrology, water use and land use was of significant influence. Two output variables are specifically dependent on the feedbacks between disciplinary modules: stored water volumes and irrigated production. The fair to good simulations of annual mean water storage in large reservoirs results indicate that the influence of water use on water availability is represented in a reasonable way at the sub-regional scale. Fair simulation of state production of irrigated crops, relying on stored water volumes, indicates that the influence of water availability on irrigated agriculture is represented in a reasonable way at the state-scale. The amount of evidence, however, allows for a quite limited validation of the SIM only. It can be concluded that SIM-simulations of sufficiency of water supply under changes in climate or under driving forces of water use at larger scales do have an internal consistency and are plausible. Simulated socio-economic impacts should only be considered to be indicative.

3.3. Selected results: climate change impacts

Selected examples of applications of SIM are presented in this section. Starting point for the climate downscaling were global climate change simulations from two GCMs, ECHAM-4 (Roeckner et al., 1996) and HADCM-2 (Johns et al., 1997). These two models differ strongly in their projections for future precipitation in Northeast Brazil.

For an annual increase of greenhouse gases by 1% per year as of 1990, projections of precipitation changes over that region (2070–2099 compared to 1961–1990) are −50% for ECHAM-4 and +21% for HADCM-2. Fig. 4 shows the precipitation trend from 1996 to 2050, scaled down to the study area of Ceará and Piauí, using the statistical method, and will be referred to as the 'dry' and 'wet' climate change scenarios.

Assessing the effects of climate change, simulations for one fixed reference scenario of regional and global developments with the two climate change scenarios were compared. The reference scenario is taken from Döll and Krol (2002) and Krol et al. (2003), and assumes a business-as-usual type of development with a regional focus on cash cropping mostly by expanding irrigated agriculture, with a consistent expansion of water storage infrastructure at current rates and on development concentration in the metropolitan and coastal areas and in the fluvial plains (industry, irrigation and recreation).

The first impact of climate change in the causal chain of processes is the impact on the availability of water resources. Precipitation changes have a direct effect on the water balance, affecting runoff generation, river flow and surface water storage.

River runoff shows a drastic decrease to precipitation changes (Fig. 5a) after 2025 for the dry scenario, amplifying relative decreases in precipitation by a factor of 2, and a statistically insignificant increase for the wet scenario. Similar tendencies appear for the water storage in reservoirs. Dam construction is one of the main regional strategies to reduce water shortages in the dry period (July–November) and to carry water availability from wetter years to following dryer years. The total water volume stored in large reservoirs with storage capacity above $50 \times 10^6\ m^3$ at the beginning of the dry season shows a strong increase between 2000 and 2015 (Fig. 5b), as a consequence of a marked increase in storage capacity (by $7000 \times 10^6\ m^3$). Total storage capacity in Ceará and Piauí then reaches almost $22{,}000 \times 10^6\ m^3$, of which

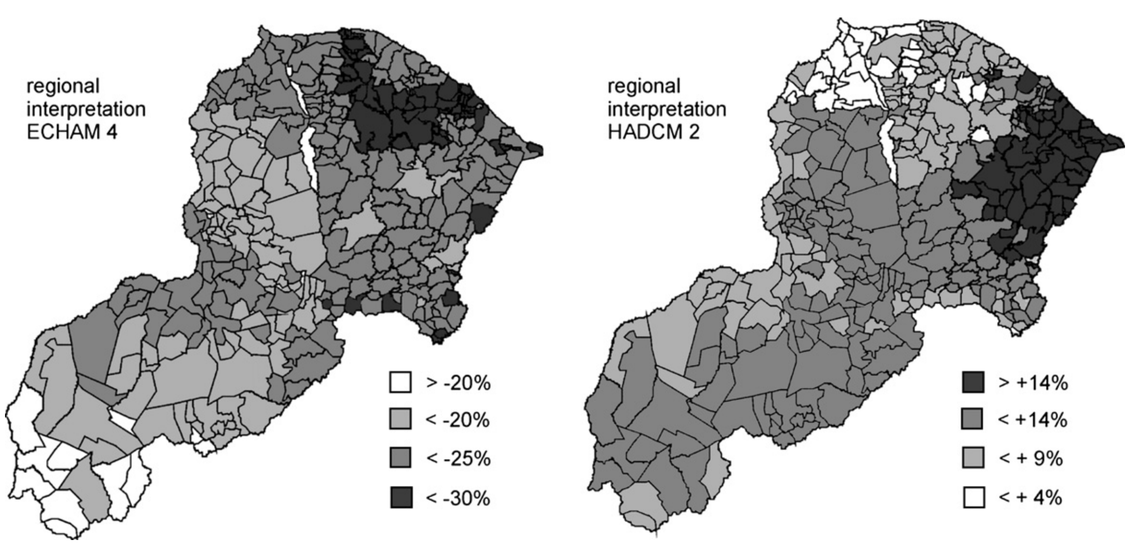

Fig. 4. Regional projections of global climate change: relative change in annual precipitation over the period 2000–2050.

$16,400 \times 10^6$ m^3 is installed in Ceará. Afterwards, in the wet scenario the reservoirs do not show a significant trend in the volume of water stored. For the dry scenario, stored volume in Ceará shows a marked decline. Here it should be noted, that in the scenario, storage capacity is increasing up to year 2025, indicating that water storage strategies that are profitable under historic or current climate conditions, may become either appropriate or costly and inefficient under a changed climate.

The general decline in water availability for the dry scenario after 2025 should be seen in connection to the trends in water use. Due to population growth, increased connection to public water supply systems, intensification of industry and, above all, a strong increase in irrigated area, water demand grows strongly in that scenario. This leads to an increasing risk for under-fulfilment of water demand (Fig. 6). In the first decades, increases in storage capacity, and higher efficiency in water use and in the usage of storage capacity can match the growing water demand and keep the fraction of fulfilled demand at an acceptable level of around 90%. In the latter two decades the level of fulfilment can only be maintained under positive developments in climate. For the unfavourable climate scenario, the levels of fulfilment partly indicate a possible inconsistency with the assumed optimistic assumptions for the developments in irrigation agriculture. But even for the irrigation areas that are in operation at present, water supply would fall short at increasing rates for the 'dry' climate scenario.

The impact of climate change on agricultural production is similarly severe for non-irrigated crops. The simulated trend in rain-fed agricultural yields shows a decrease of 12–55% in dry and an increase of 4–23% in wet, depending on the crop. Compared to underlying precipitation trends (−24% for the dry and +10% for the wet scenario), these trends are amplified by a factor of 0.5–2.

4. Conclusions

4.1. Integrated modelling and regional vulnerability

The integrated simulations showed that the approach provides a tool to explore the dynamics of the complex situation in NE-Brazil in a quantitative way, including the consideration of sensitivity to external forcing. It was possible to identify highly relevant cross-links within the system under consideration. Model applications on analysing regional sensitivity to climate change indicated how the tool can diagnose plausible impacts of assumptions on external drivers as well as possible internal consistencies within the assumptions. More specifically, the consistency of assumptions influencing water supply and influencing water demand can be evaluated.

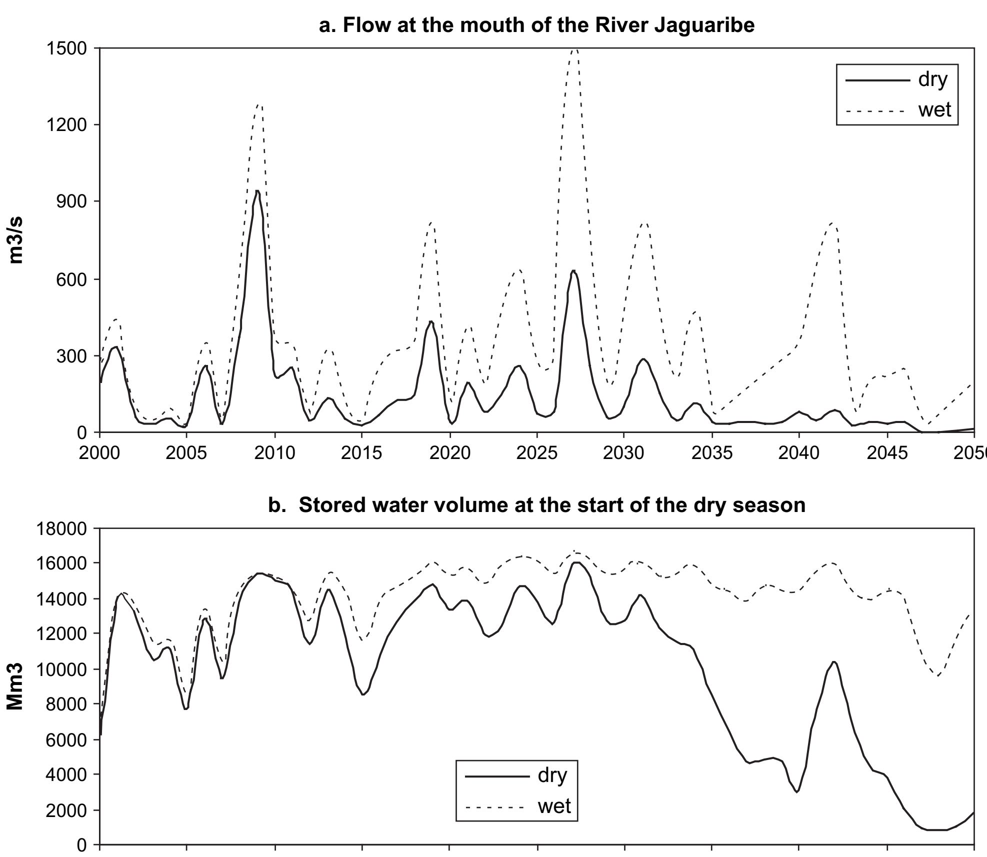

Fig. 5. Simulated impacts of climate change on regional water resources over the period 2000–2050 for regional climate change projections with a trend of increasing ("wet") or decreasing ("dry") precipitation, using a common reference scenario for water demand.

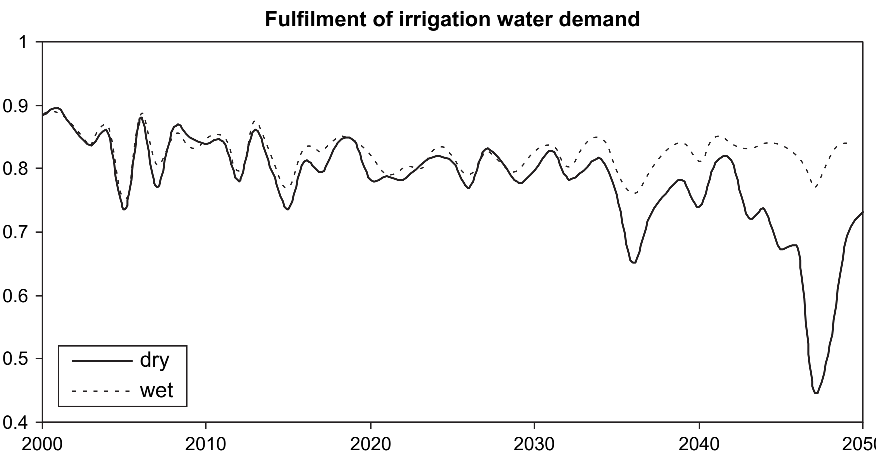

Fig. 6. Simulated relative fulfilment of regional irrigation water demand over the period 2000–2050 for regional climate change projections with a trend of increasing ("wet") or decreasing ("dry") precipitation, using a common reference scenario for water demand.

The climate scenario data analysed illustrate that current state-of-the-art projections still leave a very wide range of plausible climate developments in Northeast Brazil, where both dramatic precipitation decreases and significant increases should be considered plausible on the time scale of 50 years. This time scale of climate change is comparable to e.g. the lifetime of large water-infrastructure.

Simulations indicate that the impacts of plausible climate change have effects on water availability in a magnitude that endorses its careful consideration in long-term resource-use-related policy making (such as construction of water-infrastructure). River flow and crop production were found to be specifically sensitive, with amplifications of the relative trend of change in precipitation by a factor of up to 2 were found.

A direct coupling of climate, hydrology, surface water storage and water use was found to be very relevant for some of the output variables, especially for unfavourable scenarios, e.g. it was found that the efficiency of surface water storage in existing and newly planned infrastructure may be increasingly more marginal, and that the degree of fulfilment of water demand may not remain in its present envelope. This indicates that the sustainability of regional development along a business-as-usual pathway may critically depend on the regional materialisation of climate change.

The model was also successful in exploring potential impacts of climate change and other global change processes on crop yield and agricultural production, making evident that water is a crucial factor, and that an efficient and ecologically sound water management is a key question for the further development of this semi-arid region.

It was found, that the vulnerability of rain-fed production is high due to the already marginal local sufficiency of rainwater for crop-growth; irrigated production may become as vulnerable due to growing water demands, approaching storage capacity in combination with unfavourable developments for the inflow into reservoirs, due to climate change.

The broad variety of causes for vulnerability, indicated above, stresses the importance of the integrated modelling of climate, hydrology, and agricultural production. In regional development plans, expansion of the irrigated area serves to increase the net returns on water resources. So, in a risk-averting strategy expansion will avoid to approach levels where the reliability of a sufficient availability of water cannot be guaranteed anymore. Strategies optimizing mean returns may be more risk-accepting. In this way, strategies concerning the expansion of irrigated production are closely related to water management strategies, calling for integrated scenario analysis.

4.2. SIM as a tool for policy support

The main objective in the development of SIM has been the identification of sensitivities to climate change for a region with already marginal climate conditions, furthering the science of global change impacts.

Here it is crucial to remark that, at the start of the project, the issue of climate change was not considered as a relevant factor in regional policy at all. Climate related policy issues are plentiful, but all relate to mean conditions and, above all, climate variability. Therefore, the project did not aim at supporting concrete decision-making processes. Instead, the policy-oriented aim was to raise awareness on the relevance of the issue of climate change for regional development and to put forward approaches and potential tools on handling the issue, an aim supported by the German and Brazilian national institutions supporting the project.

To this end, the construction of a concrete Decision-Support System (DSS) was found not to be appropriate. The basic preconditions for a sensible pathway towards a DSS include an issue to be recognised as a (potential) policy issue by the main stakeholders involved (above all by the relevant policy makers), and the demand or willingness of them to use a DSS in the decision-making process. Effective application of a DSS is limited to situations where agreement exists on the objectives of the policy and the potential measures, but where consequences are not clear yet (De Kok and Wind, 2003), with e.g. gaming approaches preferred in other situations. The preconditions were not fulfilled here. Here, an integrated model was constructed, to be operated by the modellers and peers only. The policy-oriented objective of this tool was, to supply policy makers with state-of-the-art information of plausible regional climate change impacts and realistic insights in what tools and their application can convey.

Implementation of SIM in a DSS setting could be useful in future for policy issues where e.g. risks for long-term large-scale environmental management due to climate change are explicitly been taken into account. For an effective DSS, reduced form models are recommended to replace the present modules in SIM.

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