IMPETUS: Implementing HELP in the Upper Ouémé basin#

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Abstract

Regional climate models that take into account land-use changes indicate that in the future, a general decrease in rainfall, together with prominent surface heating, can be expected for sub-Saharan Africa and the region north of the Sahara until 2050. Due to high population growth, land use changes rapidly and influences water availability and water demand. In this context, the research project IMPETUS ('An Integrated Approach to the Efficient Management of Scarce Water Resources in West Africa') offers a range of options for sustainable management of different components of the hydrological cycle. Target areas are the Ouémé basin in Benin and the Drâa catchment in Morocco. This paper concentrates on the Ouémé basin.

Based on plausible scenarios of future economic, demographic, and climate developments, the effects of land use, land cover change, climate change, and demographic development on water availability and water demand are quantified. Scenarios of future water availability and water demand for the Upper Ouémé (Benin) catchment are discussed. To calculate water availability, the output of a regional climate model was linked to a hydrological model that also considered land use change calculated by a cellular automata model. Future water requirements were computed by linking population growth and per capita water demand, which was derived from a regional survey. Furthermore, the need for water for animal husbandry was considered.

The results of the 'business as usual' scenario, combined with IPCC Scenarios A1B and B2, through the year 2045 are presented. The results reveal a significant decrease in water availability (surface water and groundwater) due to a decrease in rainfall and a significant increase in evapotranspiration. Although total water consumption increases strongly, it represents only about 0.5% of the yearly renewable water resources. Comparing these data, it may be concluded that water scarcity is not a problem in Benin. However, water availability shows high temporal variations due to the rainy and the dry seasons. Even if physical water scarcity is not a limiting factor, access to water in some parts of the catchment is limited due to economic factors.

Keywords: HELP, IMPETUS, Benin, Morocco, Decision Support Systems, global change, information systems, loosely coupled models, problem clusters, scenario development, water availability, water demand

Introduction

Since the early 1970s, tropical West Africa has suffered from a prolonged drought that reached its peak in the first half of the 1980s. All climatic zones, from the semi-arid Sahel and the sub-humid Sudanese zone to the humid Gulf of Guinea have been affected. In addition, the area north of the Sahara desert has experienced a number of dry years since the 1970s. The situation is aggravated by increasing water demand, mainly due to high population growth, which reduces per capita water availability dramatically.

In order to solve present and possible future problems with regard to freshwater supply, an interdisciplinary and holistic approach is clearly necessary. This is done for West Africa in the present initiative named IMPETUS ('An Integrated Approach to the Efficient Management of Scarce Water Resources in West Africa'), a joint venture of the Universities of Cologne and Bonn, Germany. The work done within IMPETUS is part of a research programme concerning the global water cycle (GLOWA), which is financed by the German Federal Ministry of Education and Research (BMBF). The aim of GLOWA is the development of strategies for sustainable future water management at a regional level while taking into account global environmental changes and socio-economic framework conditions.

West Africa was chosen because it has experienced the most pronounced inter-decadal climate variability in the world during the 20th century; and the regions north and south of the Sahara might be linked via atmospheric teleconnection processes with regard to precipitation anomalies. The first results have provided evidence for the existence of such a link by atmospheric moisture transport out of the area of the ITCZ over the Western Sahel zone northward across the Sahara Desert towards the Atlas Mountains (Knippertz et al., 2003).

Along a transect between the Atlas Mountains and the Gulf of Guinea (Fig. 1), two river catchments were chosen according to the following criteria: feasibility (< 100 000 km^2), availability of pre-existing data sets, politically stable conditions, relevance, and representativeness in the following sense: the Drâa catchment in southeast Morocco is typical of a gradient from humid/sub-humid subtropical mountains to their arid foothills; the Ouémé basin in Benin is typical of the wet and dry sub-humid climate ('Guineo-Soudanien') of the outer tropics embedded within a transect from the Sahelian to the Guinean Coast climate.

Based on global general circulation models, the Fourth Assessment Report (AR4) of the Intergovernmental Panel on

Revised paper. Originally presented at the symposium 'HELP in Action: Local Solutions to Global Water Problems – Lessons from the South' which was held at the Emperor's Palace, Johannesburg, South Africa from 4 to 9 November 2007.

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Figure 1
The two river catchments considered in this study, namely the DRÂA catchment in Morocco and the OUÉMÉ catchment in Benin, are outlined in bold

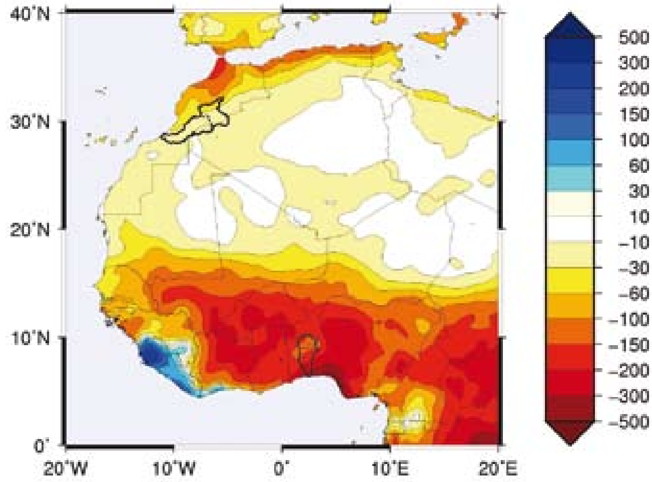

Figure 2
Results of the Regional Climate Model REMO: Projection of the change in annual precipitation over West Africa for the period 2001-2050 (from Paeth et al., 2008). Units are mm. The bold lines mark the considered catchments.

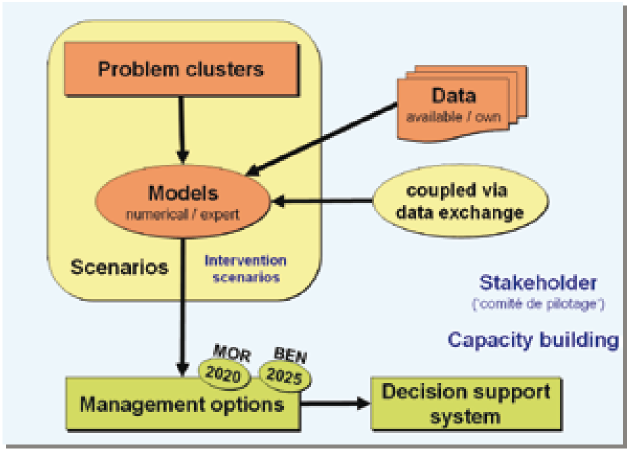

Figure 3
Schematic representation of the IMPETUS approach. The work is organised into problem clusters. Adapted models are applied to compute scenarios of further development.

Climate Change (IPCC) projects an overall warming trend for Africa and a drying for sub-tropical North Africa. The rainfall trend for tropical West Africa is uncertain. Regional climate modelling within IMPETUS (Fig. 2), which takes into account land-use changes, indicates that in the future a general decrease in rainfall, together with a prominent surface heating, can be expected for sub-Saharan Africa and sub-tropical North Africa until 2050 (Paeth, 2004). In Fig. 2, averages of six realisations of the REMO model are shown (3 realisations for the IPCC SRES Scenario A1B and 3 realisations for Scenario B1). Land-use changes, such as those due to deforestation and desertification, are taken into account in these models.

This is similar for different scenarios, in which increasing greenhouse-gas concentrations are prescribed according to the IPCC conventions. It can be assumed that anthropogenic climate change, in combination with land use changes and population growth, will impact hydro-climate with a weakening of the hydrological cycle in tropical and subtropical West Africa, with the implication that decreasing fresh water availability in regions of increasing water demand. In this context, there is a need for a sustainable management of different components of the hydrological cycle.

The IMPETUS approach

It is the goal of this research to develop *management options* for different components of the hydrological cycle, using the tools of *Spatial Decision Support Systems* (SDSS). The target years are 2025 for Benin and 2020 for Morocco. Decision making requires an exhaustive knowledge about processes, driving forces, stakeholders, and their possibilities. The IMPETUS approach is summarised in Fig. 3**.**

Decisions are complex and require an adapted technology. No single solution exists for complex decision-related questions. To handle the complexity adequately, numerous *problem clusters* were defined. These are meta-problems which require multi-disciplinary analyses in order to draw conclusions with respect to possible future developments. For nearly every problem cluster, a spatial decision support system (SDSS), an information system (IS), or a monitoring tool (MT) is developed which provides tailored tools for decision making.

Since the year 2000, IMPETUS has collected data from all available sources and has taken measurements concerning all water-related aspects. Data are stored in databases and are made available to everyone interested; an example is the provision of a Digital Atlas of Benin and Morocco. IMPETUS has developed, calibrated, and validated computer models describing the underlying processes. A number of computer models have been advanced and adapted to the investigated regions. They have covered all areas of interest, such as climatology (e.g., REMO, LM, FOOT3DK), hydrology (e.g., UHP-HRU, SWAT, MODFLOW), agriculture (e.g., EPIC, ORYZA), socio-economics (e.g., BenIMPACT, CLUE-S), and health (e.g., Liverpool Malaria Model). The models can be either *numerical* or *expert* and they are coupled via a *data exchange* ('loosely coupled

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ISSN 0378-4738 = Water SA Vol. 34 No. 4 (Special HELP edition) 2008
ISSN 1816-7950 = Water SA (on-line)

models'). An example of the application of different models for solving interdisciplinary problems is given below. IMPETUS has developed scenarios – including *intervention scenarios* – in close cooperation with project partners from Benin and Morocco (more details can be found below).

Local stakeholders participated throughout the different phases of the project. Furthermore, an intense *capacity development* of local partners is accomplished. This especially covers the development and use of the SDSS, IS, and MT at different levels (academic and institutional levels).

The present paper focuses on the Ouémé basin.

IMPETUS scenarios: Socio-economic scenarios

In order to investigate the effects of global and regional change on water resources and related issues, scenarios of regional development were developed. Scenarios are consistent and plausible images of alternative futures that are detailed enough to support the decision making process. A meaningful scenario shows different societal, ecological, and technological aspects of the system under investigation. Scenarios are not predictions and should not be qualified by a probability. Instead, they allow for the analysis and assessment of alternative development paths of complex systems.

Scenarios can be developed both qualitatively or quantitatively. It is, however, state-of-the-art to combine qualitative and quantitative analyses. Prominent examples are the scenarios of the Intergovernmental Panel on Climate Change (IPCC, 2001) or the scenarios of the Millennium Ecosystem Assessment of UNEP (UNEP, 2005). The following criteria are relevant for scenario development:

- Qualitative storylines are generated that describe not only the general characteristics of the scenario and the main driving forces, but also the degree of their mutual interaction
- The driving forces are quantified on the basis of the storylines and are used for the simulation of impacts
- The generation of storylines and the definition of indicators should be done in cooperation with decision makers and stakeholders
- Quite often, so called reference- or base scenarios, that describe possible general developments of the system under investigation, are developed first. Afterwards, intervention (or political)-scenarios are generated which analyse the influence of certain external events (war, economic crisis), policies, programmes, or single measures on the system under investigation.

The structure of the scenario development process is given in Fig. 4. Participation of societal actors plays an important role in the development of scenarios. This helps to create scenarios that are up to date; on the other hand, it prevents mistakes due to incorrect or insufficient information or a wrong interpretation of data, which can put the entire analysis into question. First, the main characteristics and scales of the scenarios were defined followed by the selection of indicators and main driving forces. In a first analysis step, a broad qualitative analysis is performed, resulting in a qualitative description of the indicators and driving forces, or the so-called 'qualitative trend-matrix'. From this description of the basic characteristics and the main driving forces, as well as their interactions, so-called narrative 'storylines' are developed, which is the basis for quantification with the help of different models. These storylines describe the main economic development, the development in the agricultural sector, the development of political framework conditions, the demographic development /life quality, and the environment and natural resources.

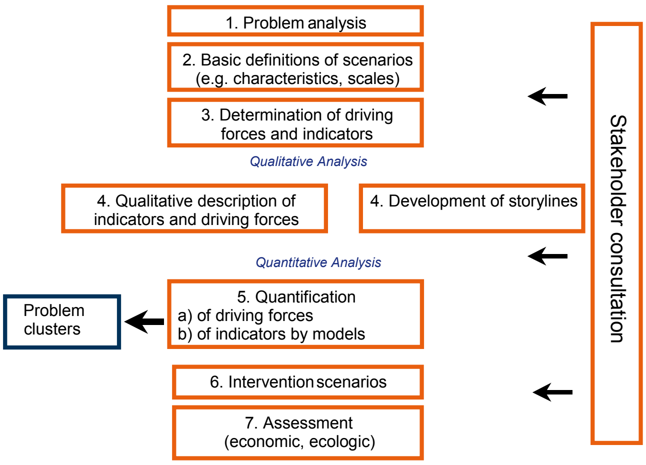

Figure 4
Overview of the scenario development process in the IMPETUS project

Basically, three different scenarios that follow different basic logics are developed. The aim was to cover a broad spectrum of possible developments. Therefore, two scenarios were developed that reflect more extreme yet realistic development paths, whereas the third scenario was constructed as a business-as-usual scenario. Climate is not an explicit thematic issue described in the above mentioned storylines. Instead, we defined three climate reference scenarios for each catchment which serve as external drivers of the more general scenarios (see below). This procedure allows for a more flexible combination of the two types of scenarios.

The three scenarios for the Ouémé catchment in Benin can be briefly described as follows (for details, see Speth and Diekkrüger, 2006):

1. Scenario B1 'Economic growth and consolidation of decentralisation' describes a scenario of political stability and economic growth. Living conditions of the population improve and the overall pressure of resource depletion decreases due to technical innovations.
2. Scenario B2 'Economic stagnation and institutional insecurity' sketches a development path of a continuing and mutually influencing spiral of political destabilisation and economic depression. Declining world market prices for the main export products, decreasing grants of donor assistance, and declining rates of regional and local economic cooperation lead to negative overall economic development which also undermines the political stability of the country. Living conditions worsen or stagnate at a low level. Resource depletion and resulting conflicts increase.
3. Scenario B3 'Business as usual' extrapolates the current trends. Against this background, economic development and social welfare does not increase in general. The country is successful in maintaining its political stability but fails in improving its position on the world markets and its overall competitiveness. Population growth continues to decline and the traditional power structures on the local level remain rather unchanged.

The temporal resolution is 5 years. The target year is 2025 for Benin. This choice is motivated by pre-existing long-term strategy papers of local governments (Bénin 2025: ALAFIA, Stratégies de développement du Bénin à long terme, Minist. de Coord. Plan. Devel. Empl.; PNUD (2000): Stratégie 2020 de développement rural, Document de Référence). For an appropriate spatial differentiation, three regions were considered in Benin: the Upper-Ouémé (characterised as a rural region with a low population density and only one annual rainy period), the Middle-Ouémé (also a rural region and the southern border of transhumance), and the Lower-Ouémé (characterised by a well-developed infrastructure, a high rate of urbanisation and high population density, and two annual rainy periods).

The three scenarios are further refined by intervention scenarios which allow the consideration of the effect of political interventions on a considered issue, such as the effect of granting a subsidy to single crops.

Climate scenarios

Research within IMPETUS has shown that not all regional climate processes are adequately represented in the numerical models. In order to cover the reasonable projections of regional climate change, three climate scenarios were defined (for details, see Speth and Diekkrüger, 2006) and chosen as external driving forces to the above-mentioned three socio-economic scenarios:

1 Scenario X – 'Process understanding' describes a climate scenario based on a thorough understanding of the underlying processes and developments. Because no mathematical model was applied, local knowledge gained in IMPETUS is a prerequisite for plausible scenario development.
2 Scenario Y – 'Climate model prediction' sketches a development of the climate until 2025 by using different climate models. The main driving forces are greenhouse gases as well as land use and land cover change. The approach is described in detail below.
3 Scenario Z – 'Persistence of recently observed trends (business as usual)' extrapolates the current trends. These trends are mainly based on the analysis of rainfall, temperature, and sea surface temperatures (SST), and consider land cover change.

For Scenario Y, computer models for simulating future development were applied. Increasing greenhouse gas concentrations as well as progressive land use changes were taken into account. The global climate modelling was performed by the ECHAM5 model and the regional (synoptic-scale, continent-wide) climate modelling by REMO (resolution 0.5°, about 55 km). REMO is a hydrostatic regional climate model developed at the Max Planck Institute for Meteorology which is nested into ECHAM. For local scale phenomena, further climate models are applied (LM, FOOT3DK) but are not further discussed here. Concerning the regional climate modelling with REMO, the monsoonal circulation over West Africa could be simulated in a more realistic and more detailed way compared with former attempts of regional climate modelling over West Africa. In particular, anthropogenic land cover changes were included into future climate scenarios for Northern and Tropical Africa. Transient regional climate simulations were undertaken in an ensemble mode (three runs) with REMO for the period 1960-2000 and for the IPCC SRES Scenarios A1B and B1 for the period 2000-2050 as the IPCC climate Scenarios A1B and B1 were available. While Scenario A1B describes a more globalised world with high economic growth, Scenario B1 is characterised by a more sustainable growth. Using these climate simulations, an analysis of model related variability (at least somewhat comparable to natural variability) and uncertainty imposed by the regional scale forcing of future climate scenarios is possible.

Problem clusters

The concrete work in IMPETUS is organised into problem clusters. The term 'problem cluster' describes a set of comprehensive and complex problems which require a multi-disciplinary approach in order to be successfully analysed and understood. Thus, when developing and implementing related solutions, the future perspective has to be considered (cf. Fig. 3). These problem clusters cover a wide spectrum of socio-economic and environmental-systemic problems and their interactions. Scenarios were fed into in the problem cluster via the boundary conditions.

The analysis of future development was mainly based on suitable models. We largely abstained from developing new models, but used existing models after having checked their suitability. The models were adapted for the specific situation in the country, sometimes also for the local level. We gathered a comprehensive collection of models which can be utilised for the different kinds of analyses needed in each problem cluster. This model collection allowed for flexibility when approaching specific research questions. The concept of IMPETUS does not foresee the development of a single coupled modelling system, but rather the loose coupling of different system components (disciplinary models) in accordance with the question being considered. Numerical models or expert models form the backbone of each problem cluster. Results of other models or problem clusters are used as input.

About 20 problem clusters were defined for the research area in Benin. They were organised in so-called thematic domains:

- Food security: A number of problem clusters deal with food production depending on soil quality and rainfall, erosion, etc. One example is the problem cluster 'Effects of land use change, climate change, and crop management on soil degradation and crop yield in the Upper Ouémé catchment'.
- Hydrology: These problem clusters are related to water availability, water demand, and rainfall prognosis. The problem cluster 'Availability and water demand in the Upper Ouémé catchment' is explained in detail below.
- Land use: In this cluster, the development of land use, land cover, and related topics are analysed. Within the problem cluster 'Land use and land cover changes in the Ouémé catchment: Detection, causes, projections, changes', scenarios of land use and land cover development are developed, which is the basis of the calculations of hydrology and erosion.
- Society and health: In addition to population projections, water management, and livelihood security, microbiological and virological aspects as well as malaria and meningitis are studied. One example is the problem cluster 'Risk assessment with regard to the occurrence of malaria in Africa under the influence of observed and projected climate change'.

Example: 'Water availability and water demand in the Upper Ouémé catchment'

Present and future water availability and water demand is analysed for the Upper Ouémé catchment, a subcatchment of the Ouémé catchment which covers an area of about 14 300 km². It is located in the sub-humid Sudan-Guinea-Zone in central Benin. This region is characterised by a unimodal rainy season from May to October with a mean annual precipitation of 1 100 mm/a.

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ISSN 0378-4738 = Water SA Vol. 34 No. 4 (Special HELP edition) 2008
ISSN 1816-7950 = Water SA (on-line)

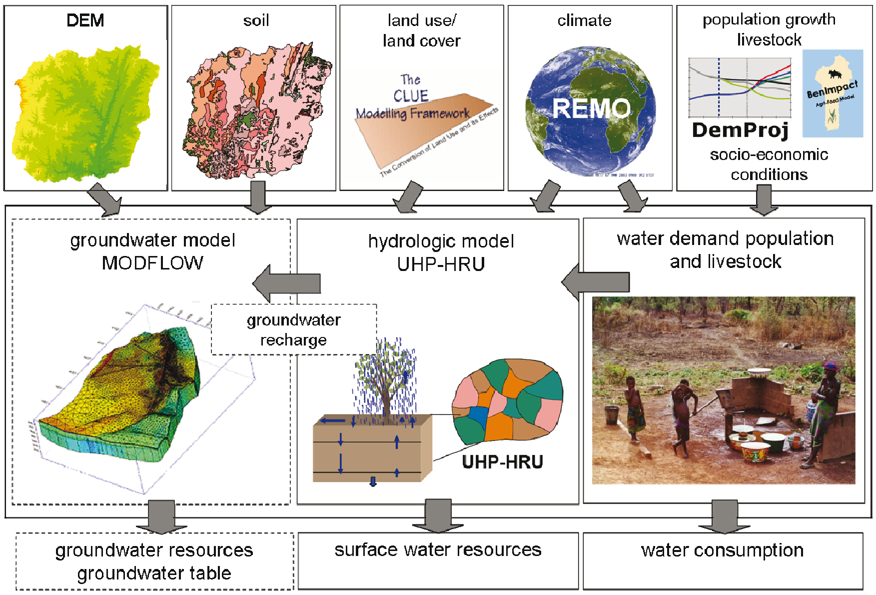

Figure 5
Interdisciplinary modelling approach to assess future water availability. Dashed lines indicate planned components.

The mean temperature is 26.4°C. Due to the lack of rainfall during the dry season, river discharge occurs only periodically from June to December.

For calculating hydrological processes and water demand projections of land-use change, demographic development and climate change are required. As shown in Fig. 5, this was calculated with different modelling approaches. In addition to the hydrological model UHP-HRU, the LUCC (Land Use and Cover Change) modelling was carried out with the model CLUE-S (Verburg et al., 2002) by the remote-sensing research group of the IMPETUS project. The climate scenarios were calculated with the REMO model. The water consumption of households was calculated using the demographic projections of Heldmann (2006) and census data of INSAE (Institut National de la Statistique et de l'Analyse Economique) in combination with data of different water use studies of Hadjer et al. (2005) and Schopp (2004, 2006). The animal water need was calculated by Gruber and Kuhn (2006) based on agro-statistical data. Details concerning these approaches and models are discussed below.

Modelling concept

In order to assess the impact of environmental and socio-economic changes on the future water resources in the Ouémé catchment, an interdisciplinary modelling approach was used. With this approach, the future natural water availability, as well as the water consumption, can be calculated. The overview in Fig. 5 shows the general outline of the problem cluster and how the conceptual hydrological model UHP-HRU was used to calculate the natural water availability. UHP-HRU is a semi-distributed model which works with hydrological response units (HRUs) as spatial discretisation (about 1 700 HRUs for 14 300 km^2). Each HRU is composed of three linear storages: the root zone storage, unsaturated zone storage, and saturated zone storage. These are linked via percolation and capillary rise. The potential evapotranspiration was optionally calculated using Penman (1956), Turc (1963), or Priestley and Taylor (1972). For computation of the surface runoff, the SCS curve number approach was used (SCS, 1972). A more detailed description of the model can be found in Giertz et al. (2006). The model was satisfactorily validated for different sub-catchments with different land-use conditions, and also for dry and wet periods (Giertz et al., 2006). Consequently, the model is also applicable for changing climate conditions (e.g., reduction of rainfall). UHP-HRU is able to consider changes in land use and is therefore applicable to study the impact of Global Change on water resources.

Land-use and cover change modelling

The LUCC modelling was performed by Thamm et al. (2005) with the cellular automata model CLUE-S (Verburg et al., 2002). The spatially explicit model was successfully tested in different tropical environments (Verburg et al., 2004; Verburg et al., 2004a).

The setup of the CLUE-S model requires probability layers for each land-cover class, conversion information, and future demand scenarios. Influences of different driving forces on land use and land cover were calculated with logistic regressions in which the distance to roads, the distance to important settlements, the population density, the soil suitability for agriculture, and the protected forest areas are used as independent variables (Thamm et al., 2005).

For the Upper Ouémé catchment, the model was validated with land use/land cover classification of LANDSAT ETM+ scenes from 13.12.1991 and 26.10.2000 (Judex, 2003). The model output for the year 2000 was compared with the LANDSAT classification data. To assess the goodness of fit, the ROC method (Pontius and Schneider, 2000) was used. This measure is similar to the R^2 for ordinary linear regressions. For the simulated land cover change from 1991 to 2000, these values were between 0.69 and 0.99 for the different cover classes (Thamm et al., 2005). Consequently, the model was able to explain the land cover change in the region with the chosen driving forces.

With CLUE-S, five different land use scenarios were calculated. Scenarios L1 to L3 were based on the IMPETUS-scenarios B1 to B3 as described before, while scenario L4 considered a higher population growth in the Upper Ouémé catchment, and L5 was an intervention scenario which assumes the construction of a new road in the catchment.

The scenarios were calculated in an annual time step. The output files are raster maps which can be used directly as input for the UHP-HRU model.

Climate modelling

As presented in Giertz et al. (2006) and described before, the climate scenarios were calculated with REMO, a hydrostatic regional climate model developed at the Max Planck Institute for Meteorology which is nested into ECHAM5 (Paeth et al., 2005). The REMO model is able to simulate time series of more than 50 years and is therefore applicable for this objective. As the resolution of the model is relatively coarse (0.5°*0.5°), a statistical downscaling approach was used to create artificial station data for each rainfall and climate station in Benin. As the hydrological model uses station data as input, this approach allows for a better incorporation of the data. The downscaling algorithm for the precipitation data is based on a probability matching approach which was combined with an orographical and stochastic term. The mean temperature was adapted orographically to a 2 m temperature, which is required in UHP-HRU. The relative humidity was also adapted according to the 2 m temperature. The 10 m wind of the REMO-grid was downscaled as well, implementing local effects of the orographic roughness. Only the global radiation was directly taken from the REMO grid cell. In order to take into account the variability of the REMO results, three model runs were simulated for each scenario with the hydrological model based on the available REMO ensemble runs. For each scenario, the mean of the three runs was taken as the result of the scenario.

Water consumption

Compared to the first water consumption assessment of Giertz et al. (2006), the data availability concerning water use in Benin was ameliorated due to further investigations by Schopp (2006) concerning household water consumption in urban areas, commercial water use, and irrigation.

Household water consumption

As mentioned before, census data from INSAE (2004) and the demographic projections from Heldmann (2006) were used as a basis for the assessment of domestic water use. The projections were calculated from 2002 (most recent census) to 2025 for the three development scenarios with the model SPECTRUM DEM-Proj (http://www.policyproject.com), which is based on area specific fertility and mortality rates. As a result, the model determined only small differences in the population for the different scenarios, which is due to the rather short time period considered here (only one generation) and the fact that more than 50% of the population is below 15 years of age and therefore is reaching the reproductive phase in the next years.

Based on the studies of Hadjer et al. (2005) and Schopp (2004, 2006), the water use per person per day was determined. The investigations of Schopp (2006) in urban areas revealed that households using tap water have a significantly higher water use than households using wells or other water sources. Therefore, the main water source of the households was taken into account to calculate the water consumption. As the national census of Benin includes data about the main water source used in the interviewed households, these data were used to classify the population of each census village according to their main water source. The population was classified into 3 groups:

1. People using mainly tap water
2. People using mainly groundwater from wells, pumps, or water towers
3. People using mainly surface water.

Based on the results of Schopp (2004), 19 ℓ/cap·d was assumed for Group 2 and 14 ℓ/cap·d for Group 3. The water consumption of tap water users varies from city to city depending on the standard of living in each city. According to a classification system of the local water provider SONEB ('Societé Nationale des Eaux du Bénin'), all 69 cities with tap water connections were classified into four groups, according to the number of water connections and the total water use of the city. Based on Schopp (2006), for each group a daily water consumption rate was determined for each class and used as the standard value for each city of the same class. Table 1 shows the classification scheme and the related water use for each class.

For the scenario calculation, the ratio of used water sources per census village was modified based on the parameters of the defined IMPETUS scenarios. The used water sources, as well as the daily water consumption per person, were modified in the different scenarios.

For the business as usual scenario (B3), the planned extension of the water supply network in each town by the SONEB was used for the determination of future tap water users. For the estimation of the water users of wells and pumps, the strategies of the development projects responsible for the rural water consumption were used. They plan to construct a sufficient number of wells each year to reach the Millennium Development Goals.

Agricultural water use

As the UHP-HRU model calculated the evapotranspiration, the water use of rain-fed agriculture was already implemented in the simulation results of UHP-HRU. Presently, irrigation is not widespread in Benin. In the Upper Ouémé catchment, no large irrigation areas exist. Water demand for livestock was calculated based on data from agricultural statistics of Benin in combination with water consumption data (Gruber and Kuhn, 2006). For the scenario calculation, the growth rate was taken from demographic projections.

TABLE 1
Classification of cities with tap water

Class	Classification criteria	Water use per capita and day [ℓ]	Cities
1	> 5 000 water connections or > 1 Mio. m³ total annual water use	80	Cotonou, Porto-Novo, Abomey, Bohicon, Parakou
2	1 000-5 000 water connections or 250 000- 1 Mio. m³ total annual water use	74	Abomey-Calavi, Quidah, Pobe, Comé, Gran Popo, Lokossa, Natintingou
3	300-1 000 water connections or 50 000–250 000 m³ total annual water use	68	Allada, Kétou, Sakété, Azové, Dogbo, Klouékanmé, Dassa, Savalou, Kandi Malanville, Cové, Djougou,
4	< 300 water connections or <50 000 m³ total annual water use	57	All other cities connected to SONEB-systems

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ISSN 0378-4738 = Water SA Vol. 34 No. 4 (Special HELP edition) 2008
ISSN 1816-7950 = Water SA (on-line)

Commercial water use

As mentioned in Giertz et al. (2006), no industry is located in the Upper Ouémé catchment. Therefore, commercial water use is very low and was neglected in the scenario calculations. For the water use assessment of the entire Ouémé catchment, it will be of higher interest.

Business as usual scenario: Water availability and water use in the Upper Ouémé catchment in the year 2025

The integrated modelling approach presented above was used to calculate the socio-economic scenarios in combination with the climate scenarios. In this first scenario analysis, the development Scenario B3 'business as usual' was combined with IPCC climate Scenarios A1B and B1. For development Scenario B3, the LUCC modelling showed an increase of agricultural area of about 80% and a related decrease of dense and sparse savannah from 2000 to 2025. The spatial distribution reveals that the expansion of agricultural area occurs mainly along roads and tracks, where the accessibility is easy. This can be explained by the modelling approach in which the access to infrastructure determines the conversion from natural to agricultural land.

Both climate scenarios showed an increase of temperature and a decrease of precipitation. For scenario A1B, rainfall decreased by about 14% and for B1 by 11% for the whole Upper Ouémé catchment, compared to the period 1993-2003. Potential evapotranspiration increases significantly up to 20% due to an increase in air temperature. Due to lower potential evapotransporation during the rainy season than in the dry season, actual evapotranspiration also increases but is not as significant as the potential. As a result, water availability decreases as rainfall decreases. As the interannual variability of the rainfall is very high in the region, only the mean water availability and water demand of decades are analysed here.

Figures 6 and 7 show the comparison of the mean renewable water resources (river discharge + groundwater recharge) of the period 1993-2003 and Scenarios A1B and B1 for the period 2015-2025. The A1B scenario shows a strong reduction of available water due to the reduction of rainfall and increased

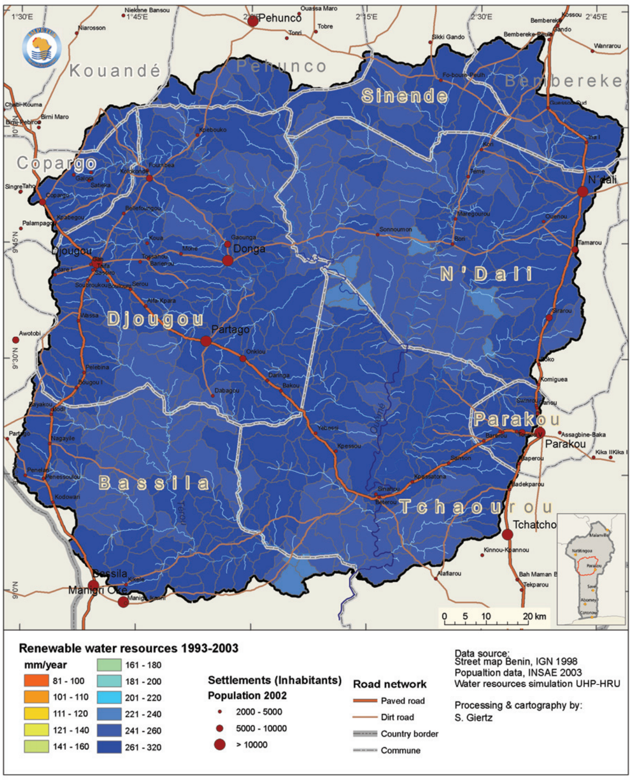

Figure 6
Renewable water resources for the years 1993-2003 in mm/a

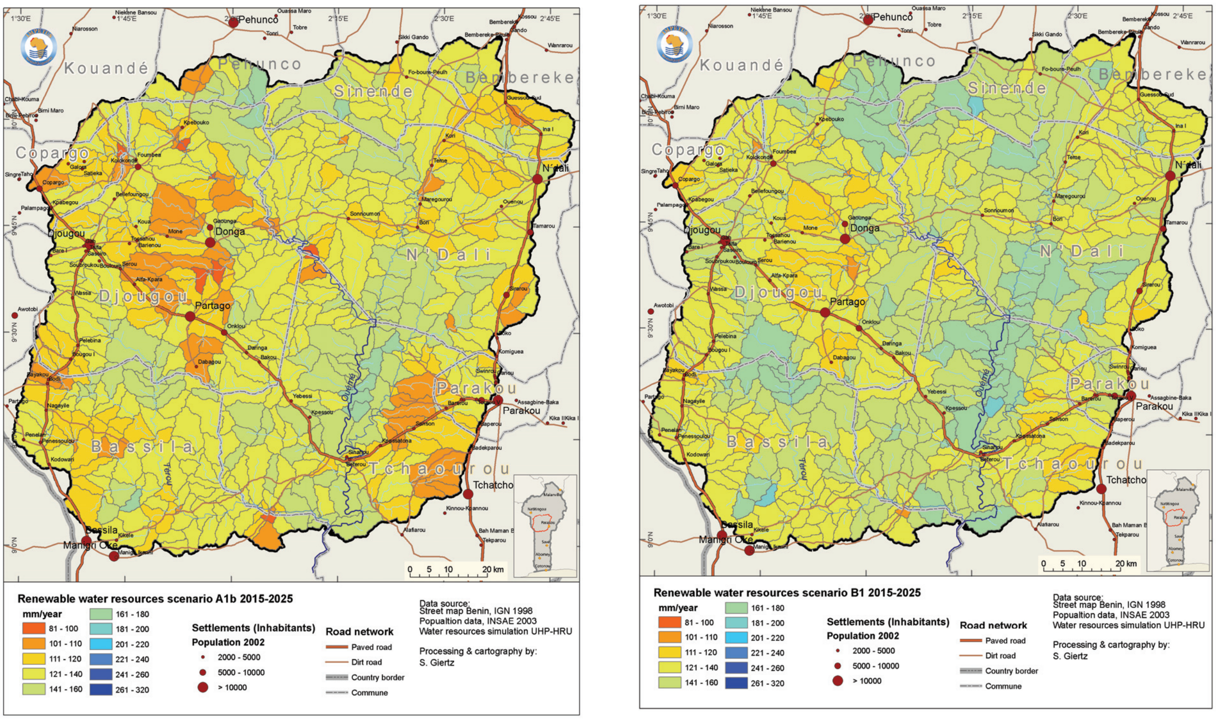

Figure 7
Renewable water resources Scenarios A1B and B1; mean values for the decade 2015-2025, in mm/a

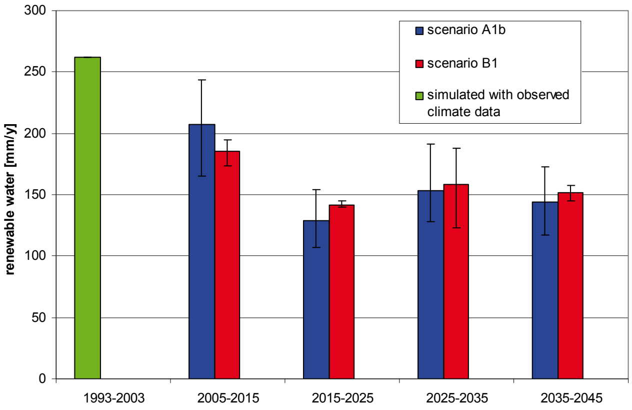

Figure 8
Renewable water resources in the Upper Ouémé catchment. Shown are the means of the three ensemble runs with the minimum and maximum of the three runs.

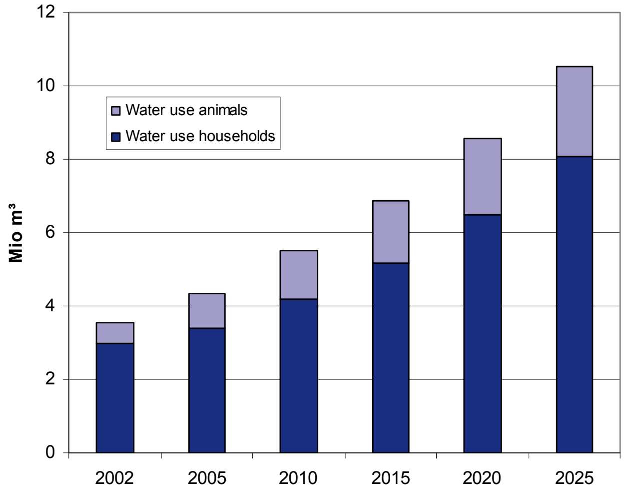

Figure 9
Total water consumption in the Upper Ouémé catchment for Scenario B3

temperature. For Scenario B1, the reduction of available water is less significant than for scenario A1B. While for the whole HVO the mean water availability is about 262 mm/a for the decade 1993-2003, only 129 mm/a was simulated for Scenario A1B and 141 mm/a for Scenario B1 (2015-2025). Projected mean discharge is much lower than expected from a 11 to 14% decrease in precipitation. This can be explained by the fact that the mean runoff coefficient in this area is presently about 0.24, and a 10% reduction of rainfall with comparable ETact values results in a runoff coefficient of about 0.13. For water availability, differences in land use changes are as least as significant as climate change. In the LUCC modelling approach, it was asssumed that protected areas such as protected forests are still unaffected from land use change. Furthermore, the areas surrounding larger cities like Parakou and Djougou are already used as agricultural land and therefore no further conversion can be expected. All these processes lead to a significant increase in spatial disparities which tighten water scarcity.

In Fig. 8, the comparison of the total renewable water resources per decade is shown for both climate scenarios. As the climate scenarios were calculated through 2049, the decades 2025-2035 and 2035-2045 were also simulated. Due to a lack of land use modelling results for this period, the land use remained constant from 2025-2049. As described before, the climate model was run three times for each scenario, resulting in six climate scenarios (ensemble mode). To consider the variability in climate data, the hydrological model was applied to each of the climate scenario. Therefore, it was possible to consider and to evaluate the uncertainty in the climate modelling. As shown in Fig. 8, the variability from decade to decade is high. Except for the period 2025-2035, the variability in the B1 Scenario is larger than that in the A1B Scenario. Overall, interannual variability is large in West Africa, which is reflected in the climate simulation and the hydrological model results. Therefore, long-term simulation as analysed here is a prerequisite for an appropriate evaluation of the development of water resources.

In Fig. 9, the total water consumption for Scenario B3 is shown. Although it was assumed that an increase in per capita water demand per day is low, the increase in total water demand is high due to high population growth. Benin experiences a population growth of about 3.2%, which results in a doubling of the population about every 22 years, although locally the population growth can be much higher due to migration. The values are higher for domestic water use compared with the first assessment of Giertz et al. (2006) because supplementary data of urban water use were implemented.

The calculations of Gruber and Kuhn (2006) revealed that the water needed for livestock is four times higher in 2025 compared with 2002, which is caused not only by an increase in the number of livestock but also by an increase in water consumption by the animals, due to higher air temperatures.

Conclusion

In the presented modelling, the future water availability and water consumption of the Upper Ouémé catchment was assessed in an interdisciplinary scenario analysis. With the combination of LUCC, climate, demographic, and hydrologic modelling with water consumption investigations, all impacts on the future water availability could be assessed. The results revealed a significant decrease in water availability (surface water and groundwater) due to the decrease in rainfall and a significant increase in evapotranspiration.

Although the total water consumption increases strongly, it represents only 0.57% of the yearly renewable water resources of the catchment in 2025 for Scenario A1B, and 0.51% for Scenario B1. Comparing these data, it may be concluded that water scarcity will not be a problem in Benin. Water availability shows a high temporal variation due to the rainy and dry seasons. Even if physical water scarcity is not a limiting factor in some parts of the catchment, access to water is limited due to economic factors. Groundwater is often not accessible because many villages lack wells. Instead of groundwater, river water is used, but as this water is contaminated with dangerous bacteria, it cannot be considered as drinking water of appropriate quality. In the dry season, the surface water is not available, and shallow aquifers dry out. Only people having access to deep wells, pumps, or tap water are able to secure water for the entire year.

HELP - Hydrology for the Environment, Life and Policy - is a joint initiative of the United Nations Educational Scientific Organisation (UNESCO) and the World Meteorological Organisation (WMO). It is a new approach to integrated catchment management through the creation of a framework for water resource managers and water scientists to work together on water-related problems. In this context, the research project IMPETUS was launched, which provides knowledge, data, models, and SDSS

Available on website http://www.wrc.org.za
ISSN 0378-4738 = Water SA Vol. 34 No. 4 (Special HELP edition) 2008
ISSN 1816-7950 = Water SA (on-line)

for local decision makers. IMPETUS is an example of interdisciplinary research which involves local stakeholders and local knowledge to enable the persons concerned with water problems to assess the effects of their decisions.

The presented modelling approach for water availability and water consumption in the Upper Ouémé catchment is one example of the research carried out. Based on plausible scenarios, the effects of land use and land cover change, climate change, and demographic development on water availability and water demand were quantified.

From the scenario calculations, it is clear that until 2025 water scarcity is not a problem on the regional scale in Benin. The main problems are the annual distribution of water (dry season vs. rainy season), the local water resources (wells), the water infrastructure, and the water quality. Although the regional hydrological investigations cannot directly help here, they are the fundamental basis for water resource management within an integrated river basin management structure which is required to cope with further issues.

Acknowledgements

The authors would like to thank the German Ministry of Education and Research (BMBF, grant No. 01LW06001A and 01LW06001B) as well as the MIWFT North Rhine-Westphalia (Grant No. 313-21200200) for the funding of the IMPETUS project in the framework of the GLOWA program. The authors would also like to thank all IMPETUS scientists for providing the data, information, and modelling results used in this study. Special thanks go to the CATCH-project and the Direction Générale de l'Eau (DGEau) in Benin, who provided the discharge and precipitation data for the Upper Ouémé catchment, and to all other partners in Benin.

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