Christoph, M. P. Speth, M. Bollig, J. Burkhardt, B. Diekkrüger, G. Menz, M. Rössler & W. Schug (2007): Two examples towards the efficient and sustainable management of scarce water resources in North-west and West Africa. In: Lozán, J. L., H. Grassl, P. Hupfer, L. Menzel & C.-D. Schönwiese. Global Change: Enough water for all? Wissenschaftliche Auswertungen, Hamburg. 384 S. Online: www.klima-warnsignale.uni-hamburg.de

4.4 Two examples towards the efficient and sustainable management of scarce water resources in North-west and West Africa

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SUMMARY: *In the IMPETUS project thorough investigations of all aspects of the hydrological cycle are carried out within two river catchments in West Africa: the wadi Drâa in the south east of Morocco and the Ouémé river in Benin. This choice is motivated by the indications found that since the 1970s the droughts north and south the Sahara have been related. In order to solve possible future problems with regard to freshwater supply, a clearly interdisciplinary approach is taken. The underlying method is demonstrated exemplarily on the basis of two pressing problem clusters*

Shortage of freshwater is expected to be the dominant water problem of the 21st Century and one that, along with water quality, may well jeopardise all other efforts to secure sustainable development, and even in some cases lead to social and political instability. Freshwater has already become critically scarce in many regions. Some estimates suggest that today the amount of freshwater available for each person in Africa is only about a quarter of that in 1950 (OBASI 1999), and that freshwater supply could become problematic especially in parts of North-west and West Africa, where about 30 years of drought have been observed. The physical mechanisms responsible for the variability of climates in these regions are still relatively poorly known and understood. The possibility of human-induced climate change adds additional serious aspects to the challenging water-related problems already encountered in many parts of the world.

Motivation

In order to solve present and possible future problems with regard to freshwater supply, a clearly interdisciplinary and holistic approach is necessary. This is done for West Africa in the present initiative named IMPETUS, a joint venture of the universities of Cologne and Bonn, Germany.

In the first three-year phase the focus was mainly on the diagnosis of different aspects of the water budget and their interactions. Based on this, in the second three-year phase methods were developed to assess the bandwidth of changes expected during the coming decades. In the final three years the collected insights of all the disciplines involved will be used for the development and provision of operational tools for local decision makers. Such decision support systems will allow stakeholders to assess risks and likely impacts on the local and regional scale.

Choice of catchments

West Africa was chosen because (i) it has experienced the most pronounced inter-decadal variability of climate in the world during the 20th century, (ii) relations to the climates of Europe might exist via complex atmosphere-ocean interactions in the area of the tropical/ subtropical and north Atlantic ocean, and (iii) the regions north and south of the Sahara might be linked via atmospheric teleconnection processes with regard to precipitation anomalies; first results give evidence for the existence of such a link by atmospheric moisture transports out of the area of the ITCZ over the Western Sahel zone northward across the Sahara towards the Atlas mountains. (KNIPPERTZ et al. 2003).

Along a transept between the Atlas Mountains and the Gulf of Guinea (*Fig. 4.4-1*) two reasonably sized 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 the south-east of Morocco is typical of a gradient from humid/sub-humid subtropical mountains to their arid foothills; the Ouémé basin in Benin is typical of an alternating sub-humid climate (»Guineo-Soudanien«) of the outer tropics embedded within a transept from the Sahelian to the Guinean Coast climate.

Past and present situation

Moroccan precipitation is strongly related to the large-scale atmospheric circulation over the subtropical and extratropical North Atlantic and the Mediterranean Sea, with the bulk of precipitation occurring in winter between November and March). Since the late 1970s, Morocco has experienced a number of extremely dry winter seasons, the causes of which are not fully understood. Against this background, the development of sustainable water resource management is even more a necessity. The considered wadi Drâa possesses two main tributaries, the wadi Dades and the wadi Ouarzazate which drain the south-eastern and the south-western parts of the Atlas and confluence near the city of Ouarzazate thereby forming the wadi Drâa. At the site of confluence construction of a storage lake was completed in 1972 with an original storage capacity of 560 million m^3. Due to strong sedimentation a capacity of

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only 440 million m³ remains today. Approximately 250 million m³ of stored water is released in normal years for irrigation purposes. The irrigated perimeter covers a total area of approximately 26,500 ha. Since the snow melt in spring contributes significantly to the annual discharge of the main storage lake tributaries, diagnosing the spatial distribution of accumulated snow water equivalent in the elevated areas of the catchment is particularly desirable. An effective and sustainable management of water in the Drâa valley is essential to enable the competing users (water power generation, irrigation, domestic consumption) to have adequate supplies, and to prevent social tensions related to water resources.

Since the early 1970s tropical West Africa has suffered from a prolonged drought that reached its first climax in the first half of the 1980s. The average rainfall deficit over 1971–1990 was of the order of 180 mm/year compared with the interval 1951–1970. All climatic zones, from the semi-arid Sahel and the subhumid Sudanese zone down to the humid Gulf of Guinea, have been affected. The prolonged West African drought has already brought about a profound deterioration in the economic and social development of the West African countries. As a consequence river discharges in West Africa have decreased by about 40–60% in recent decades, causing shortages in river water available for domestic and agricultural purposes. As a consequence this has led to extensive migrations in the past. During the rain-rich fifties, water power stations were built in the Guinea coast zone to supply a substantial amount of energy to West African countries. Low discharges of the main tributaries are the main reason for frequent shortages in energy production experienced in recent years.

Apart from the decreasing availability of freshwater *per capita* both in Morocco and in Benin the current situation north and south of the Sahara is also characterised by increasing population (population growth rate more than 3% per year), increasing degradation of the natural vegetation due to overgrazing (Morocco), demands in fire wood, and shifting cultivation (Benin). As a consequence soils quickly erode in Morocco (to a lesser degree also in Benin) and salt contents rise due to inadequate irrigation practices. In combination the aforementioned factors are likely to accelerate the degradation and desertification processes for the coming decades.

Method

Due to the importance of the hydrological cycle regarding the availability of freshwater, its different components and their interactions were identified in its complexity and quantified in the course of the first three-year phase of this project. In an integrated approach a sequence of existing models (both numerical and expert models) of the individual disciplines involved have been adapted and validated in order to describe the relationships and dependencies within the hydrological cycle in its present state. Local conditions and problems of each catchment also had to be taken into account. Basic research was only carried out if existing competence and experience proved to be insufficient.

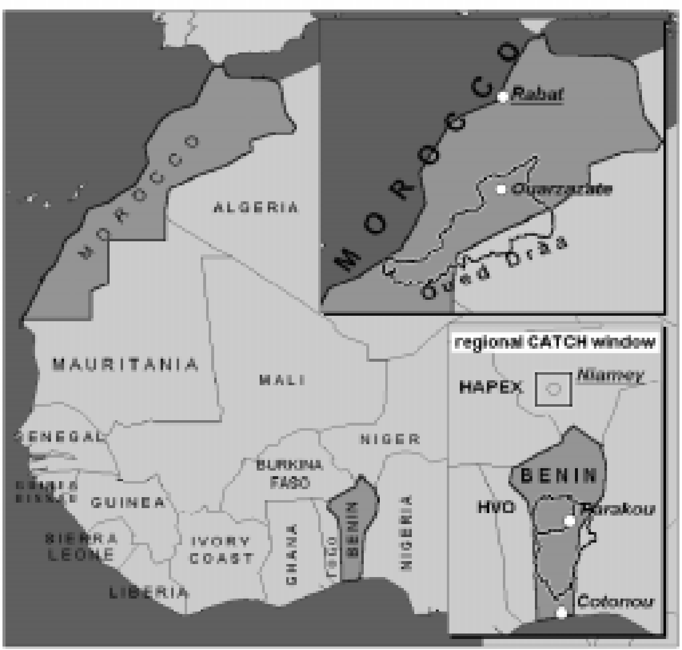

Fig. 4.4-1: The two river catchments of consideration: The DRÂA catchment in Morocco and the OUÉMÉ catchment in Benin are boldly bordered.

After the project had begun in 2000 it turned out that the pre-existing data bases were poor or incomplete for the needs of some of the disciplines involved. In these cases intensive data acquisition campaigns and surveys were carried out especially in the field of socio-economy, anthropology and medicine. For the better adaptation and validation of the numerical models of the natural sciences the existing national monitoring networks were enforced in some parts by installing measurement instruments along the height gradient in Morocco and by setting up a so called »super test site« in Benin.

In the ongoing second three-year phase (starting in 2003) the focus is set on future development. This is done on the basis of coupling suitable models. Since the integration of coupled models in a single system seems too complex disciplinary models will be loosely coupled depending on the questions to be addressed. Due to the large uncertainty of models the future cannot be predicted precisely. Therefore the bandwidth of future developments has to be assessed with the help of likely scenarios. This will also serve as a basis for assessment of suitable management options for decision makers. In a first step coarse scenarios will be designed based on the general development in the countries under consideration and in agreement with local stakeholders. In a second step these coarse scenarios will be regionalised and detailed for specific problems. The design of scenarios will take into account the following aspects: climate change, socio-cultural change, institutional change, population dynamics, economic development, and technological innovation. The scale-dependent assessment (in time and space) of future development constitutes the indispensable foundation for the design and implementation of management tools needed for decision makers in the course of the last three-year phase (starting in 2006).

Definition of problem clusters

In this study we named a whole set of related central issues a »problem cluster«. These issues can be analysed and predicted only in a multidisciplinary approach. Adequate solutions for problem clusters must be found and also implemented. The identification of problem clusters, the development of scenarios and the elaboration of solution strategies requires a close co-operation between local institutions and organisations, i. e. local stakeholders, and scientists. A problem cluster comprises a large number of individual thematic issues, each one reflecting a disciplinary process.

For the assessment of problem clusters so called »response indicators« must be defined. These indicators are metered quantities which describe the behaviour of the system in an integrated manner. As an example we take the population's food supply (units in kJ/day), an indicator where aspects of both food production and population dynamics play an important role. The assessment of scenarios can be done both in a qualitative manner (e.g. indicator will rise or fall) and in a quantitative manner (e.g. 20% decrease of a certain indicator when precipitation amounts decline by 10%). The development of solution strategies requires first the definition of critical thresholds of response indicators (e.g. recommended nutrient intake is 10,000 kJ/(day×person) according to WHO) in order to assess the success of a certain strategy.

When analysing problem clusters one has to decide which thematic issues, i.e. which processes and process chains, have to be considered. In other words one has to find out which processes influence directly or indirectly the response indicators. The thematic issues (processes) can be described by so called »status indicators« which characterise the state of the system. These state indicators are either measured directly (e.g. size of a farm in ha) or captured qualitatively (e.g. hierarchy in a village).

The principal steps undertaken when tackling problem clusters as defined in this project will be clarified by giving two examples, one for Morocco and one for Benin:

Example 1: Human influences on water- and land-use in the Drâa catchment, Morocco

South-eastern Morocco faces an increasing scarcity of available freshwater, not only due to climatic changes and the degradation of soils and vegetation cover during the recent dry periods, but also because of human interferences. In this example we are trying to analyse the environmental as well as the anthropogenic impact on water availability. As in most problem clusters developed from a social sciences background, conceptual expert models based on qualitative data are used to systematise the findings, because qualitative analyses better relate to questions regarding human intentions and interactions than numeric calculations. Quantitative methods and measurements were applied where necessary and meaningful (e.g. for measuring water consumption), but could often only be used as a sample.

Beside the focus on the human sphere given in this problem cluster, IMPETUS follows a strictly interdisciplinary approach. This procedure is necessary to identify and describe the interrelationship between human activities and the natural environment. The wide range of topics covered, like the socially defined potential and actual water availability, the quality of drinking water, the salinisation of agricultural surfaces, or the choice of optimised crops, could only be investigated by using an integrated, interdisciplinary approach. The analysis of the status quo during the first phase of IMPETUS was an important precondition for the execution of the present problem cluster:

In the Drâa catchment processes of socio-economic change are directly influenced by the declining water availability on the regional and local scales. At the same time patterns of access to water are being modified. On the domestic level, an increasing water use per head together with a growing individualisation of water rights, leading to the reorganisation of social hierarchies, are the consequences (Ait Hamza 1997). The enhanced social dynamics of the society directly alters the access to water. Case studies carried out in different oases of the Drâa Valley prove that the growing fragmentation of settlements causes ever smaller residential units or households, correlated with an increase in water consumption *per capita*. The continuously growing labour migration is one reason for this development (Lazaar 1997, Mter 1997). Money reflux from migrants is enhancing the progress of technological innovation in the home villages. Modern houses equipped with water consuming home appliances are constructed, or the money is invested in the agricultural sector in order to dig deeper wells and to purchase motor pumps. The communally owned traditional irrigation canals (»seguia«) are almost abandoned and only used occasionally, when water is discharged from the dam near Ouarzazate.

Nevertheless, in this socially as well as environmentally heterogeneous region, systems of water management depend on ethnicity, social status of individuals or groups, and on specific economic strategies applied by water consumers. Innovations, like the increased use of motor pumps for irrigation, already altered this relationship. In some regions the control over the water resources depends more on the monetary status of individuals or households than on the consent of the community.

The increased use of wells and pumps has numerous negative effects on the environment and the society (c.f. Liebelt 2003):

a) a decline of the groundwater table, which already causes losses of harvest in some regions, b) an increased salinisation of the groundwater, making the remaining water unusable for domestic or agricultural purposes, c) the break-up of communal resource management strategies (Leveau 1985), because of the accentuation of individual or household interests, d) the polarisation between independent, uncontrolled private water use and the intended state control over water resources through water-users-associations (AUEA), and e) the shift of social hierarchies with an inherent potential for conflict.

The increasing number of urban migrants, caused by the difficult state of agricultural production, has already created a fatal cycle concerning water consumption and management: Labour migrants returning financial means and cultural ideals to their rural homes, have initiated technological and social innovations leading to a higher private water consumption of a larger number of households of a smaller size. At the same time the situation of water supply is worsening. A larger number of conflicts about water between households or groups of different socio-economic status will result. This forces additional parts of the population to abandon agriculture, and to migrate to the cities. The growth of the urban population in Morocco during the last decade was remarkable, and also urban water demand is increasing. Paradoxically, the water consumption is further augmented by an improved infrastructure which supplies more individual houses with drinking water, like in the regional centre Ouarzazate.

The identification and description of social and political developments, as well as the valuation of the relevance of these developments is an advantage of expert models deployed by social sciences. At the same time the output of the models can be used to create storylines and to stimulate the direction of scenario calculation producing recommendations for local stakeholders.

Example2: Assessment and modelling of land use and land cover change in the upper Ouémé catchment

The motivation for another problem cluster lies in the fact that strong land use and land cover changes in West-Africa have taken place within the last three decades. Main causes are agricultural colonisation, growth of settlements, deforestation and desertification. These processes are triggered predominantly by the very high population growth (up to 3,5%) and changes in the regional climate for which evidence has been given.

The overall very high conversion rates of savannah to agricultural land in the Sudanian Zone, have serious impacts on processes in the ecosystem, biochemical cycles and affect therewith the life of the indigenous people.

Due to the fact, that the vegetation is a key parameter within the hydrological cycle, negative feedbacks between the changes in the vegetation cover and the regional climate can be expected.

In order to react appropriately to these serious environmental changes, there is a strong demand in precise information about future developments. This information base enables local and national decision makers to derive realistic scenarios for sustainable planning.

In most West African countries governmental institutions often have only little information concerning land-use and land cover. This increases the value of independent sources of information. In this matter remote sensed data are very important for the derivation of the temporal / spatial land use and land cover change pattern. In general vegetation changes can be correlated with the spectral reflectance, the thermal emission or the backscatter (micro-waves) of a destined surface. Based on that principle

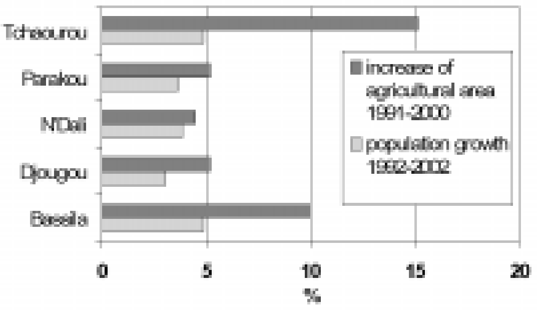

Fig. 4.4-2: Development of agricultural area and population of 5 different commune in the area of the Upper Ouémé between 1991 und 2000 (the assessment of the agricultural area was performed with LANDSAT satellite data).

land use and land cover changes can be detected with comparatively high precision by comparing multi-temporal remotely sensed data.

In the framework of the IMPETUS project a model concept for the computation of land use and land cover changes under different boundary conditions was set up. Hereby a model cascade of three models in different spatial resolution and complexity was created. On the local scale for an area of 70×20 km along the road Woubérou – Bassila (Central Benin), the land use and land cover change is computed with the model CLUE-S (Verburg et al. 2002) in a spatial resolution of 90×90 m. The model is able to interrelate to different sets of raster data, like population density or distance to waterholes with a logistic approach. For an initialisation of the model detailed surveys of more than 200 households had been carried out. The results of this investigation on a large spatial scale will be used for a parameterisation of the regional model for the entire Ouémé catchment with a cell size of 500×500 m (CLUE-model). The coupling of the local model (CLUE-S) with the regional model (CLUE) particularly enables the transfer of results which have been gained on very detailed input data to larger areas where the data base is poorer. It is possible to estimate the loss of information due to the transition to a smaller spatial scale.

As a third model layer a cellular automata based model is used for detailed studies and for an improvement of the process understanding. (Riedl & Kalasek 1998).

Within the first project phase it was possible to determine the increase of agricultural land in the Upper Ouémé Catchment between 1991 and 2000 with a precision of 83% (Judex et al. 2004). Within this period the increase of agricultural land by clear cutting of forests was up 15% (*Fig. 4.4-2*).

To model future land use and land cover based on likely scenarios a sound knowledge of the ecological and socio-ecological system variables are a precondition. Therefore, in a first step, actors and their motivation to change land use and land cover are identified, using different sources of information. That process is verbalised in so called storylines. At the same time correlation analysis of the observed land use / land cover change and the causing factors are performed. In this work step the spatial relation of the different input data is a critical aspect. Spatial not explicit data, like statistics for the administrative units (e.g. prefectures) and spatial explicit data, which have a precise determination in a spatial raster, must be regarded differently.

Final remarks

Especially in Africa water scarcity is one of the major challenges of the 21st Century. In this context the research initiative IMPETUS wants to offer sustainable solutions by using an interdisciplinary approach. Imminent problems are defined on the basis of so-called problem clusters and analysed with the help of models. Research is carried out in three steps: (1) analysis of the present state, (2) assessment of future development based on scenarios and (3) implementation of decision support tools for stakeholders. Existing tools or those under development are mentioned exemplarily in this paper. The processing of additional problem clusters will follow ♦