



IMPETUS¹ West Africa

***An integrated approach to the efficient management of scarce water resources
in West Africa:***

Case studies for selected river catchments in different climatic zones -

***An interdisciplinary proposal of the University of Cologne, the University of Bonn
and the German Aerospace Centre (DLR)***

S t a t u s R e p o r t

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¹ IMPETUS: Integratives Management-Projekt für einen Effizienten und Tragfähigen Umgang mit Süßwasser



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IMPETUS

OVERVIEW

I M P E T U S West Africa

AN INTEGRATED APPROACH TO THE EFFICIENT MANAGEMENT OF SCARCE WATER RESOURCES IN WEST AFRICA - CASE STUDIES FOR SELECTED RIVER CATCHMENTS IN DIFFERENT CLIMATIC ZONES -

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Key words: Hydrological cycle, global change, West Africa, river catchment, integrated approach

Abstract:

In Northwest and West Africa an increased occurrence of drought years since the early 1970s has brought a number of serious problems related to the fresh water supply. An integrated approach dealing with all aspects of the hydrological cycle is performed in the presented project. Investigations are carried out on the basis of two river catchments: the wadi Drâa in Morocco and the Ouémé river in Benin. During the first phase factors influencing the hydrological cycle have been identified and analysed. Different global change scenarios will be used in the second phase to predict the bandwidth of consequences regarding the fresh water supply on the local and regional scale. In the final two years the collected insights of all the disciplines will be coupled in order to assess management options and to install operational tools for the decision-making process (so called "Decision Support Systems").

Introduction:

Fresh water has already become critically scarce in many regions of the world. It is forecast that, for the first quarter of the 21st century, about one-quarter of the world population will suffer from severe water scarcity. For Africa some estimates suggest that already now the amount of fresh water available for each person is only about a quarter of that in 1950, and that fresh water supply could become problematic especially in West Africa, where about 30 years of drought have been observed. Although the climates of West Africa are still relatively poorly known and understood, it is recognised that Northwest and tropical West Africa have experienced the most pronounced inter-decadal variability of climate in the world during the 20th century. 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:

The available fresh water is controlled by the hydrological cycle. Climate, in particular the spatial and temporal distribution of precipitation and evaporation, plays a significant role in the hydrological cycle, and climate data are therefore of the utmost importance in the analysis

of ground and surface water supply for domestic and industrial users, irrigation, hydropower generation and ecosystems. Dealing effectively with the hydrological cycle and its impacts demands not only a strong co-operation between different disciplines within the natural sciences (e.g. hydrology, meteorology, botany, agriculture, geology, remote sensing), but also consideration of socio-economic and medical issues; all disciplines involved have to interact in a complex and co-ordinated manner. Hence, in order to solve possible future problems with regard to fresh water supply, a clearly interdisciplinary approach is necessary. This is done in the present initiative for West Africa and it is the purpose of this project to offer concrete ways of translating into action scientific results through scientifically-based strategies. This approach will provide a reliable basis for political measures and international agreements. In the first three-year phase the focus is set on the identification and analysis of influencing factors regarding different aspects of the water budget. Based on this, in the second three-year phase methods will be developed to predict changes during the coming decades. In the final two years the collected insights of all the disciplines will be coupled in order to assess management options and to install operational tools for the decision-making process (so called "Decision Support Systems").

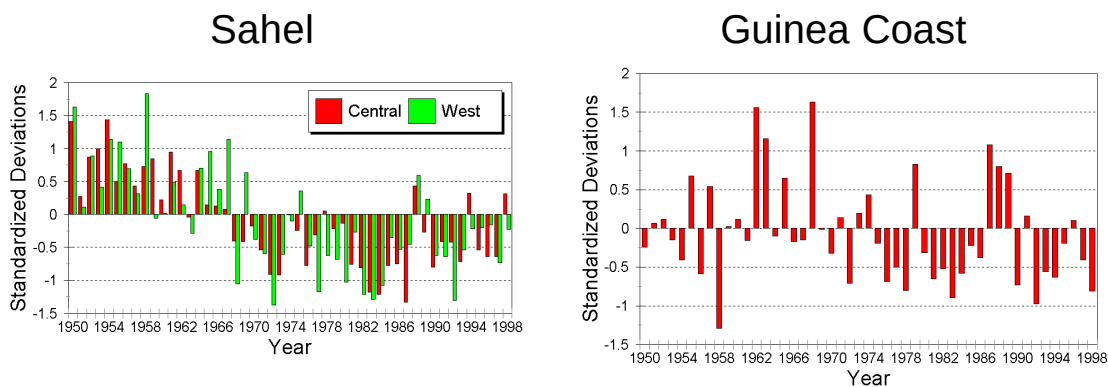


Fig. 1a Precipitation variability in West Africa for the period June - September 1950-1998.

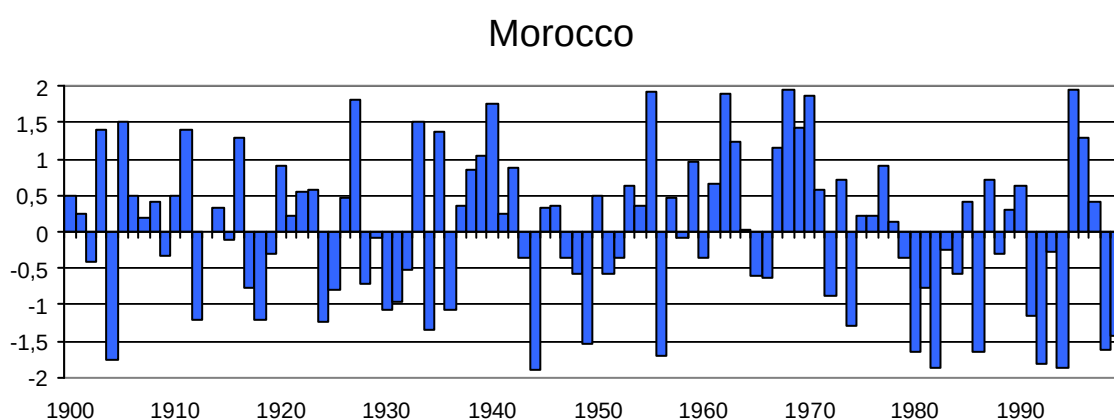


Fig. 1b Annual precipitation variability in Morocco throughout the 20th century.

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, and (iii) the regions north and south of the Sahara might be linked via atmospheric teleconnection processes with regard to precipitation anomalies; first results of subprojects A1 and B1 give strong hints for the existence of such a link by atmospheric moisture transports out of the West Sahel zone across the Sahara towards the Atlas mountains.

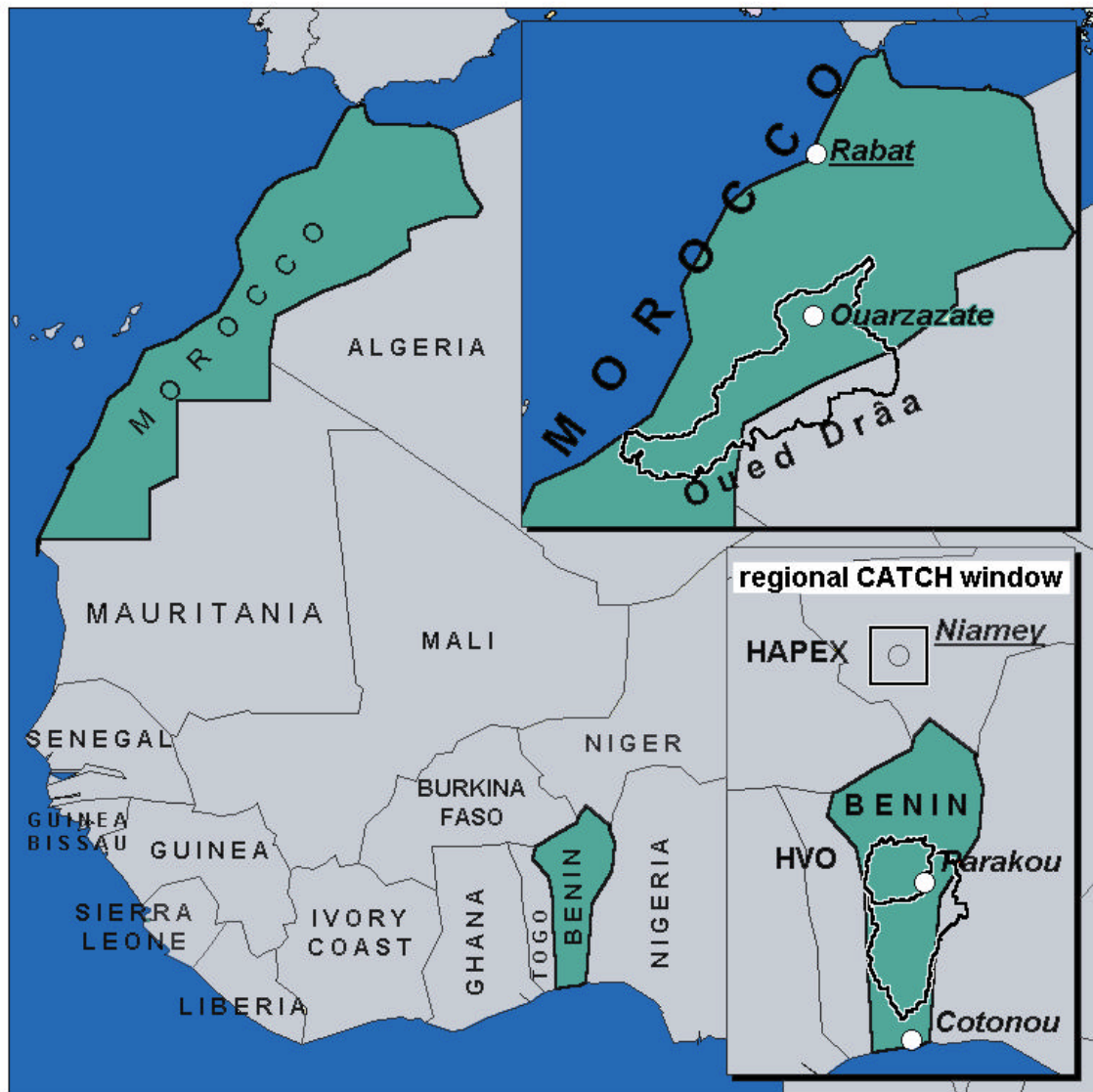


Fig. 2 The two catchments of consideration. The DRÂA catchment in Morocco and the OUÉMÉ catchment in Benin are boldly bordered. A sub-catchment of approx. 100x100 km west of Parakou (Haute Vallée de l'Ouémé: HVO) has been chosen as an area of focused investigations.

Since the 1970s both subtropical Northwest Africa and tropical West Africa have experienced a general rainfall decline which have probably been related (Fig. 1). For this reason it is of advantage to consider both areas north and south of the Sahara desert in a combined approach, realised by means of a transect between the Atlas mountains and the Gulf of Guinea (Fig. 2). This transect contains two reasonably sized river catchments ($< 100.000 \text{ km}^2$) which are representative 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 (see project B of this report); the Ouémé basin in Benin is typical of an alternating sub-humid

climate ("Guineo-Soudanien") of the outer tropics embedded within a transect from the Sahelian to the Guinean Coast climate (see project A).

The feasibility of the presented initiative has been guaranteed by the good availability of data of both the natural and the human sciences and by politically stable conditions in the respective countries.

Past and Present Situation:

Since the early 1970s tropical West Africa has suffered from a prolonged drought that reached its first climax in the first half of the eighties. 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. For example, 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. For instance Fig. 3a shows the decrease in run-off of the Ouémé at Bétérrou which reflects the integral for the southern part of the upper Ouémé catchment. 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 Ivory coast, Ghana, Togo, Benin and Nigeria.

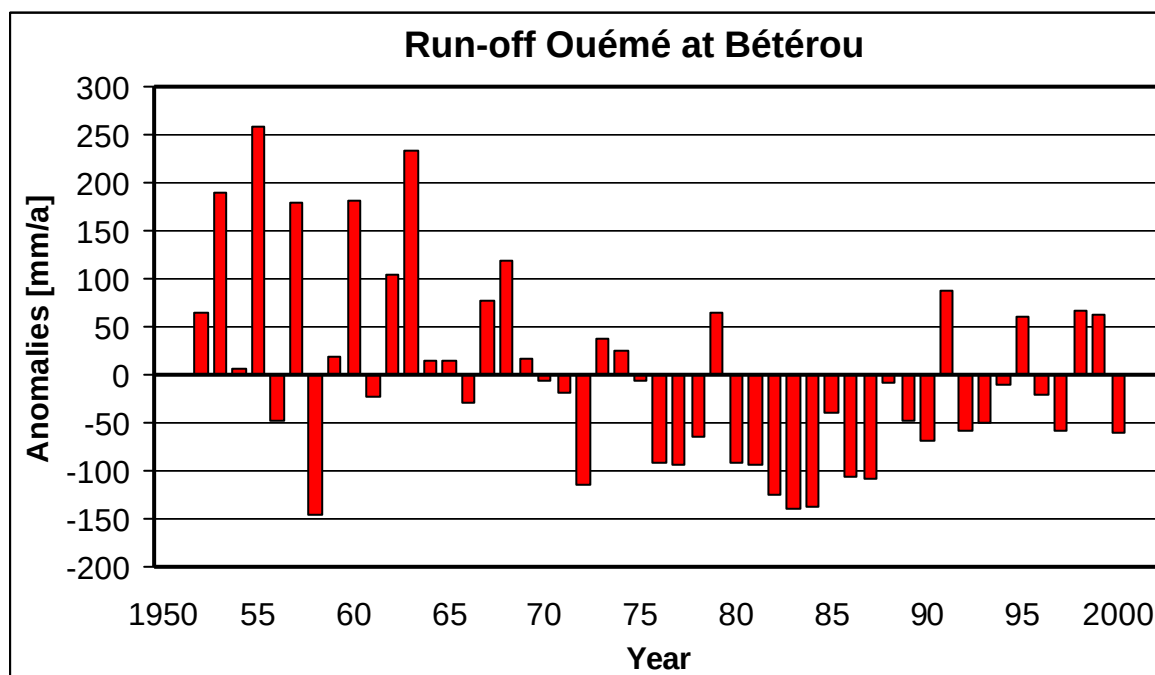


Fig. 3a Annual run-off anomalies of the Ouémé river at Bétérrou for the period 1952 through 2000. Units are in mm/year, thereby taking into account the size of the upstream catchment area.

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 (November - 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 which drain the south-eastern and south-western parts of the Atlas and meet near the city of Ouarzazate. This is also the site of the Mansour Ed Dahbi dam that was built in 1968 and whose reservoir has a storage capacity of 530 million m³. Approximately half of this amount is released in normal years. The main irrigation structures consist of five smaller dams downstream and a complex network of canals. Since the snow melt in spring contributes significantly to the annual discharge of the Drâa, 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. Fig. 3b shows the dramatic decrease in the filling of the reservoir in the last two years.

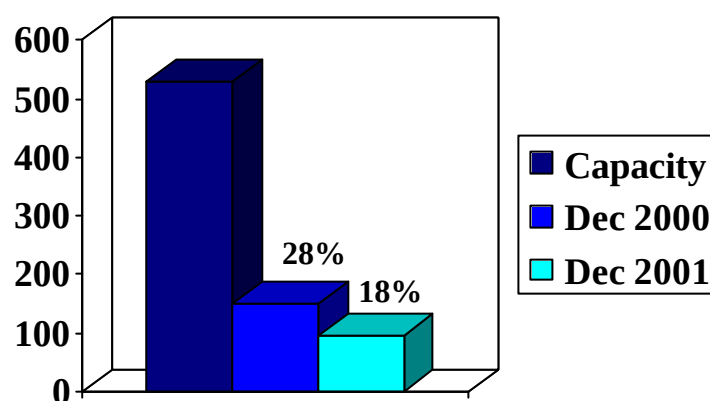


Fig. 3b Recent filling levels of the "Mansour Ed Dahbi" reservoir near Ouarzazate, Morocco.

Methodology:

The availability of fresh water is governed by the hydrological cycle. The different components and their interactions are considered in individual subprojects: the atmospheric variability in subprojects A1/B1, the continental hydrosphere in subprojects A2/B2 and the land surface processes in subprojects A3/B3. Human activities related to fresh water are investigated in subprojects A4/B4 and A5. In an integrated approach a sequence of existing models for the individual components have been adapted in the first project phase. These models will be coupled in subsequent phases with the ultimate goal to develop a decision support system. A measurement network of necessary parameters has been set up in data sparse areas. For the Ouémé catchment we concentrated on the upper Ouémé valley where the existing national and IRD hydrometeorological networks have been enforced with focus on a super test site 'Aguima' near Doguè (Fig. 4a). In the Drâa catchment 11 climate stations and 10 fenced vegetation plots were installed along a height gradient from the High Atlas to the pre-Saharan desert (Fig. 4b).

Co-operation:

Our research initiative is embedded within the local research structures of the countries where the research work is concentrated, i.e. predominantly Benin and Morocco. A large number of co-operation contracts with local institutions in these countries provide a sound basis. In

 Direction Météorologique Nationale (DMN, Benin)

 Direction de l'Hydraulique (DH, Benin)

 Institut de Recherche pour le Développement (IRD, France)

The circle indicates the 60 km radius of the French X-band radar at Djougou (planned for 2003).

During the period May - September 2002 IMPETUS will operate a radiosonde station at Parakou.

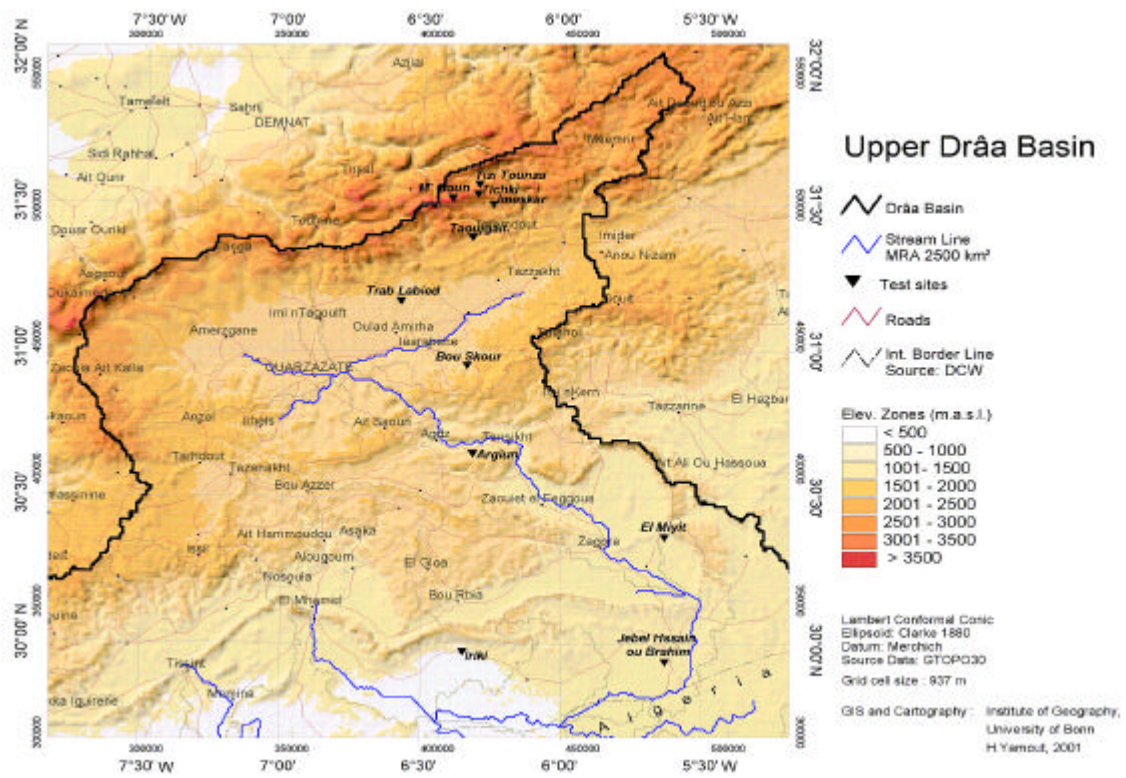


Fig. 4b Location of the IMPETUS measurement sites in the Drâa catchment in Morocco

PROJECT A

THE HYDROLOGICAL CYCLE OF THE OUÉMÉ CATCHMENT AND SOCIO-ECONOMIC IMPLICATIONS

DIAGNOSTICS AND MODELLING OF THE SPATIAL RAINFALL VARIABILITY ON INTRASEASONAL TO DECADEAL TIME SCALES

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Key words: precipitation analyses, squall lines, remote sensing, model nesting, seasonal forecast, land surface changes, scale interaction

Abstract:

Analysis of precipitation trends reveals no return to normal or above-normal monsoon rains in all climatic zones of West Africa. During recent dry decades, shortfalls at the height of the rainy seasons were the major cause for the annual rainfall deficits in central-north Benin. In this region, African easterly waves (AEWs) were found to be a major trigger mechanism for squall lines (SLs) at the peak of the rainy seasons 1998 and 1999. A 0.25 x 0.25° monthly rainfall climatology is currently enhanced to daily resolution using METEOSAT Infrared (IR) imagery and a passive microwave rainfall algorithm has been successfully calibrated with the TRMM radar. As one result of studies with the general circulation model, ECHAM4, a combination of large-scale predictors were identified and used in a multiple cross-validated statistical model which demonstrates a remarkable forecast potential of almost 50% of seasonal rainfall variability. The use of the regional model LM for case studies of typical rainfall events on different scales enhanced the understanding of West African weather variability. Idealised and complex modelling studies with the FOOT3DK clearly disclose that it is the interplay of convection cells with both land surface processes and larger-scale atmospheric dynamics that eventually determines the rainfall anomaly pattern.

Results:

Precipitation trends in Benin

A standardised rainfall anomaly index for Benin as a whole, and the three overlapping sub-regions, South Benin (6-9°N), Central Benin (7.5-10.5°N) and North Benin (9-12°N) has been developed from quality-checked historical daily rainfall data. From the rainfall indices, it is evident that a return to normal or above normal rainfall has not occurred in Benin. On the contrary, a slight negative trend emerges in recent years that is strongest at the Guinea Coast. This statement holds true for West Africa as a whole. At present, it remains unclear why the shift to a positive phase of the Atlantic decadal SST mode, that has occurred around 1995 and that favoured above-normal rainfall in West Africa in the 1950s and 1960s, has not led to a return to wetter years across West Africa. A vegetation feedback is just one, but a plausible, scenario for this behaviour.

Synoptic wave disturbances (AEWs) and squall lines (SLs) in West Africa and Benin

Using ECMWF analyses, TRMM and DMSP passive microwave sensors and METEOSAT three-hourly IR imagery, 81 African Easterly Waves (AEWs) and 344 Squall Lines (SLs)

were manually identified and tracked over West Africa during May-October 1998 and 1999. SLs triggered by AEWs were defined as such SLs that were first detected on satellite images ahead of the AEW trough and, only in the Sahel ($> 12.5^{\circ}\text{N}$), in the region of the low-level moist northerlies. While 42% AEW-SLs were diagnosed for West Africa as a whole, this number is only 27% for Benin. The reasons are twofold. Firstly, 17 out of 83 SLs occurred already in May when the AEW activity is negligible. Secondly, AEWs grow in amplitude towards the Atlantic coast, but also in the course of the season. As consequence of the seasonal amplitude growth, the number of AEW-SLs in Benin rose to 48% in the July-September period. For the dry period, 1971-1990, it was found that shortfalls at the height of the rainy season in central-north Benin (August/September) were the major cause for the annual deficits. Thus, the causes for “dry” AEWs at the height of the rainy seasons are presently investigated.

Remote sensing and precipitation analysis

The principal aim of the use of meteorological satellite data within the IMPETUS project is the establishment of a satellite based rainfall monitoring system for northwest Africa with a special emphasis on the state of Benin. This requires the derivation of rainfall on instantaneous to climatological time scales using data from different types of radiometers (e.g. microwave and infrared) as well as rain gauge data. The results will be used to assess the quality of rainfall predictions provided by different meteorological models on different spatial and temporal scales. For the hydrological subprojects within IMPETUS, the satellite based rain information can be used as input to hydrological models in different river catchments. The climatological satellite products will also be delivered to the socio-economic parts of the project giving much better geographical rainfall distributions compared to maps derived from common station based measurements.

As a starting point the precipitation analysis for Benin consisted of analysed monthly aggregated precipitation fields. For this product the monthly precipitation estimates given by the CRU ($0.5^{\circ} \times 0.5^{\circ}$ spatial sampling) and the GPCC ($1^{\circ} \times 1^{\circ}$ spatial sampling), both based solely on rain gauge measurements, and the GPCP ($2.5^{\circ} \times 2.5^{\circ}$ spatial sampling), which is a merged satellite data product, were combined in a weighted sense. The weights were computed by transferring the error covariance given by the GPCP data set (which gives a parameterised estimate of the sampling error) to the other input grids. In the next step the measurements of the individual rain gauges within the Benin weather service and the CATCH networks were taken to enhance the resolution to $0.25^{\circ} \times 0.25^{\circ}$. During the data merging process the optimal set of parameterisations of other influencing factors, e.g. orography influences on monthly rainfall was found via a cross validation technique (“regression screening”). A temporal refinement towards daily values using METEOSAT IR imagery is currently under development.

The currently used quasi empirical baseline passive microwave algorithm (Bauer et al., 2002) is extended for the use with data from the TRMM satellite. The used technique makes a first order approach to remove seasonally varying surface contributions by maps of clear-sky temporal averages of brightness temperatures. The influence of more dynamic parameters like surface temperature and moisture is reduced by successive subtraction from the observations by means of principal component analysis. The resulting index of precipitation is then calibrated to a rain rate using collocated radar data from the same satellite. It was found that the functional dependence of the precipitation index and the radar-derived rain rate is very similar for different months and years. This is an encouraging result because the temporal and spatial stability of this calibration is of paramount importance for potentially transferring the calibration function to other passive microwave radiometers e.g. SSM/I and AMSR which is necessary to enhance the temporal sampling of passive microwave based rainfall estimates.

The use of all available microwave radiometers will then establish the first version of the rainfall monitoring system at the end of the first project phase in early 2003.

Model results

A scale-comprehensive understanding of the mechanisms that cause rainfall variability in West Africa is the principal purpose of the meteorological model chain within IMPETUS. By co-ordinated model studies, the key interactions of the manifold processes that contribute to rainfall variability are identified and evaluated on all relevant temporal and spatial scales. This characterisation is the prerequisite to assess critical influences of possible global and regional changes on rainfall in the IMPETUS regions. In addition, the model chain is used to replenish meteorological information to fill observational gaps. The model hierarchy that covers the cascade from global to local scales consists of ECHAM4 (global climate model), REMO, (regional climate model), LM (regional meso-scale-? to -? forecast model) and FOOT3DK (meso-scale-? to micro-scale-? research model). Each model can be forced by passive nesting into its larger-scale counterpart. Alternative forcing can be provided to REMO and LM by analysis data.

ECHAM4 is studied and compared with other climate models such as HADAM2 to investigate global and large-scale teleconnection patterns, the long-term variability from decadal to centennial time scales and the prospect of climate prediction. Special emphasis is put on the role of global sea surface temperature (SST) changes and increasing greenhouse gas (GHG) concentrations for West African rainfall fluctuations. The results represent a deciding factor for the forcing of smaller-scale atmospheric (A1) and hydrological (A2) models and might also enter in economic balancing and agricultural planning (A4). SST is a main factor in determining West African precipitation, especially south of the Sahara. The strongest link occurs to the tropical Atlantic and works via energy fluxes at the surface and large-scale monsoon dynamics (cf. Camberlin et al. 2001). Furthermore, there is a significant teleconnection to the tropical Pacific basin, involving the ENSO phenomenon. All predictors are combined in a multiple cross-validated statistical model and demonstrate a remarkable forecast potential of almost 50% of seasonal variability. In terms of rising GHG, there is a weak but statistically significant climate change signal in Sub-Saharan rainfall which is consistent with different coupled climate models and standing out against internal variability (cf. Hulme et al. 2001). This signal consists of steadily increasing annual rainfall into the future and contrasts the 20th century drought tendency.

Synoptic processes, which are not resolved in the global models, are picked up by the regional model REMO. This model is run at 0.5° resolution over the whole West African subcontinent and helps to understand the regional-scale synoptic mechanisms which induce rainfall variations over Benin and adjacent regions. REMO can be forced by either (re-)analyses or ECHAM4 data, and supplies the forcing data for smaller-scale atmospheric (A1) and hydrological (A2) models. Present simulations reveal a reasonable representation of the observed climate variability. REMO even reproduces some basic features of observed anomalous wet and dry rainy seasons in Benin.

The relation between mesoscale features of typical precipitation systems and synoptic-scale flow patterns is investigated with the non-hydrostatic mesoscale weather prediction model *Lokalmodell* (LM) of the German Weather Service (DWD). For this purpose, the model is forced by analysis data for the global weather prediction model GME acquired from the DWD. It operates on model areas with grid sizes ranging from 0.25° (synoptic scale) down to 1 km (mesoscale) and can be used for case studies of a few days up to a couple of weeks. One important question with respect to simulation quality is if the convection parameterization, which accounts for the largest part of the model rain in West Africa, performs well in the area of interest. Two important conclusions could be made: Firstly, deficiencies of the rain forecasts are mainly caused by insufficient initial data due to the sparse network of

aerological stations in West Africa; secondly, even on smaller scales the use of a convection parameterization precipitation improves forecasts compared to using model scale physics only. The use of the LM for case studies of typical rainfall events on different scales enhanced the understanding of West African weather variability. Another important aspect is the current refinement of the land cover characterisation in co-operation with subproject A3.

The effect of interactions between the earth's surface and the atmosphere on fresh water availability in the Haute Vallée d'Ouémé (HVO) is the focus of investigations with the non-hydrostatic mesoscale model FOOT3DK. A combination of idealised ensemble simulations with a column version of the model and complex modelling of real precipitation events is employed to assess the sensitivity of precipitation to variations in the land surface. For the complex simulations, FOOT3DK is nested into LM forcing fields. Idealised studies exhibit a dominant influence of initial soil water content and an enhanced dependence of precipitation on vegetation when soil water availability is reduced. For wet soils, parameters that determine the intensity of near-surface turbulence are dominant. Complex modelling confirms that these relationships are useful to identify critical land use changes in realistic settings. However, the resulting regional structure of precipitation anomalies (Fig. A1-1) cannot exclusively be attributed to the pattern of hypothetical land use changes. It is the interplay of convection cells with both land surface processes and larger-scale atmospheric dynamics that eventually determines the rainfall anomaly pattern. Sensitivity analysis with FOOT3DK will be incorporated into a statistical-dynamical approach based on a classification of characteristic regimes that account for the rainfall in the HVO. This methodology will enable a regional assessment of rainfall reduction risks by future land use changes.

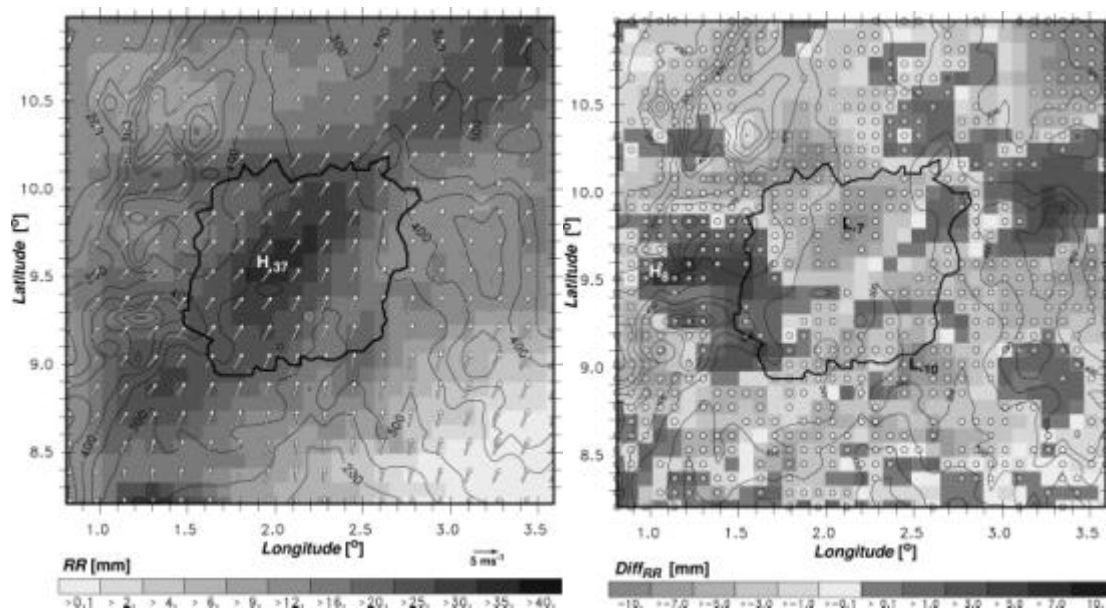


Fig. A1-1 Left: Accumulated precipitation and temporally averaged near-surface wind from July 28, 06 UTC to July 30, 06 UTC simulated by FOOT3DK for an undisturbed surface. Right: Differences in resulting for the same event if adverse properties for rainfall (reduction of vegetation, soil water, roughness; increase of albedo) are introduced at the grid points that are marked by dots.

References:

- Bauer, P., D. Burose, J. Schulz (2002): Rain detection over land surfaces using passive microwave satellite data. *Meteorologische Zeitschrift*, 11, 37-46.
- Camberlin, P.; Janicot, S. & Pocard, I. (2001): Seasonality and atmospheric dynamics of the teleconnection between African rainfall and tropical sea-surface temperature: Atlantic vs. ENSO. *Int. J. Clim.* 21, 973-1004.
- Hulme, M.; Doherty, R.; Ngara, T.; New, M. & Lister, D. (2001): African climate change: 1900-2100. *Clim. Res.* 17, 145-168.

Subproject A2

SOIL WATER DYNAMICS, SURFACE RUNOFF, GROUNDWATER RECHARGE AND SOIL DEGRADATION ON LOCAL TO REGIONAL SCALE

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Key words: catchment water fluxes, water balance, hydrological modelling, soil degradation, local to regional scale, scenario analysis, soil water dynamics.

Abstract:

The main task of the hydrological project A2 of IMPETUS is the description and quantification of the hydrological processes at different scales in Benin, West-Africa. It is the main goal to provide a hydrological modelling tool which enables us to perform a scenario analysis to assess the effects of environmental and anthropogenic change on the hydrological processes.

To attain this goal, a nested approach is used. At the local scale a representative, conjoint catchment has been selected by all working groups which acts as a super test site. It has been arranged for instruments by all groups to comprehend the interrelations of properties and processes in the subhumid tropics. In particular the subproject focuses on the variability of soil water dynamics, groundwater recharge and soil degradation.

Based on the local scale measurements and the improved insight into the interrelations of properties and processes, hydrological model applications are performed at the local scale. Due to the fact that the meteorologists within IMPETUS already use the TOPLATS model (Famiglietti & Wood, 1994) as part of their atmospheric circulation models it has also been selected as hydrological model. At the local scale the model parameters can be measured directly or derived from mapping campaigns. Parameterisation schemes are developed which are needed for the regional scale hydrological modelling which have to be based on operationally available data (soil maps, land cover classifications) stored in a Hydro-GIS.

Results:

Measurement concept

The Aguima catchment (30km²) has been selected as a super test site of IMPETUS. It is situated in the south of the upper Ouémé basin (ca. 14.000km²). The catchment (ca. 250-320m above sea level) is part of a large plain and is dominated by savannah vegetation and agricultural used areas close to villages.

All measurements performed at the local scale are concentrated in this super test site (see fig. A2-1). During the first field campaigns the following permanent instruments have been installed:

- ?? two climate stations (plus one additional of subproject A3),
- ?? two dual soil water measurement stations under four different land use types (tensiometers and TDR-probes at different soil depths, suction cups),
- ?? 32 TDR tubes covering the whole catchment area,
- ?? four discharge measurement stations,

?? 12 erosion measurement plots.

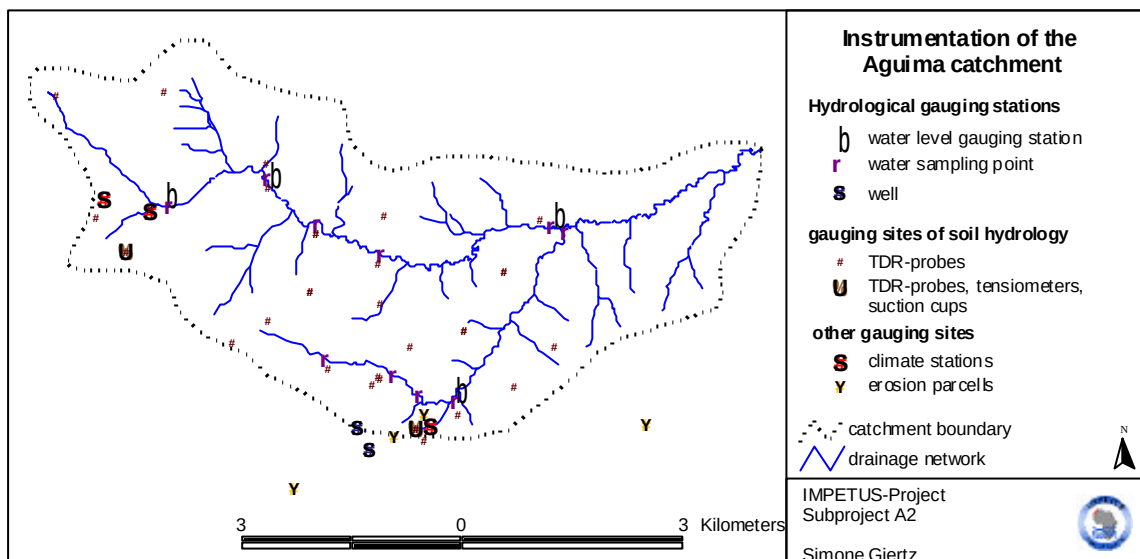


Fig A2-1: Hydro-climatological instrumentation of the super test site (Aguima catchment).

Additional to the permanent instruments a large number of campaigns have been carried out to determine soil-physical (e.g. K_s , K_u , pF , bulk density) and soil-chemical properties (e.g. nutrients, pH), to investigate the soil erosion process and to analyse the water chemistry of soil water, groundwater and surface water. One essential task to complete the knowledge on properties and processes at the local scale is the generation of the local soil map which is derived from 30 distributed profile holes and 410 drillings along transects.

Soil water dynamics

The data collection of the soil water measurement stations contributes to the analysis of the soil water dynamics related to the site properties such as soil and vegetation characteristics. The two soil water measurements stations are built up under different vegetation types, savannah and agricultural area. Both stations consist of eight tensiometers and eight TDR-probes in four depths, therefore two sub-sites are measured at a time. Additionally the spatially distributed TDR tubes enable an analysis of the spatial soil moisture pattern within the catchment which is mainly caused by soils, vegetation and topography.

The savannah site is divided into two sections with differently dense tree population ('savanne boisée' and 'fôret clair'), at the agricultural site the soil water dynamics under maize and cotton is investigated. Maize and cotton are the predominant field crops in that area, 'savanne boisée' and 'fôret clair' are the predominant natural vegetation classes. Based on these measurements the estimation of the runoff production and groundwater recharge mechanisms depending on the site properties is feasible. First measurements show a quick reaction of storm events on soil moisture and runoff (Fig. A2-2).

Soil degradation / erosion

Actual soil erosion is examined at different scales during the whole rainy season. Erosion plots have been installed to measure erosion rates at the point scale, sediment traps and erosion pins to study the spatial pattern of soil erosion. As the highest erosion rates were expected on agricultural used areas, maize, peanut, cotton and yam fields were selected for installation. One extensively pastoral used savannah site was chosen as a reference.

The amount of eroded soil material strongly depends on the amount and the intensity of the rainfall events. Highest soil loss rates are observed during heavy rainfall events. Differences

between the erosion rates of different cultures (Fig. A2-3) have mainly two reasons: the soil loss of maize, cultivated in rows, is higher than soil loss of yam cultivated on mounds. In the end of the rainy season the relation changes due to the development of the leaf area index and the soil coverage by the canopy.

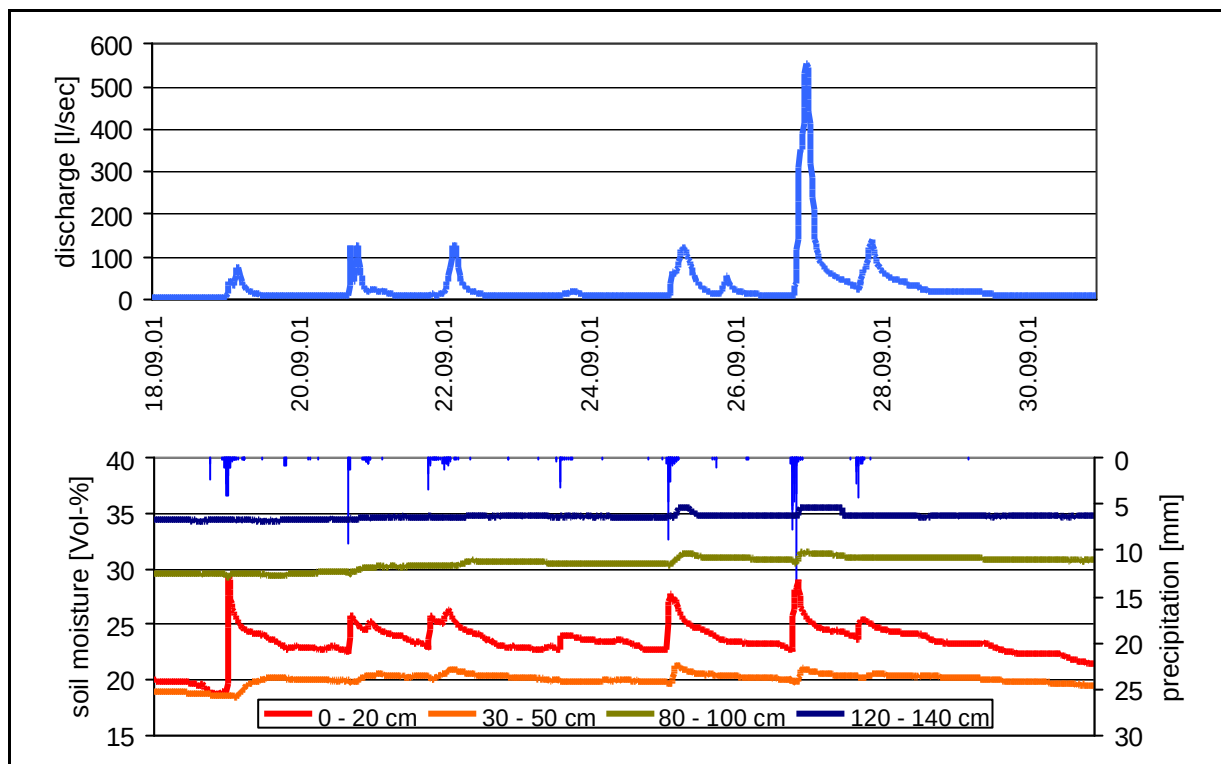


Fig. A2-2: Comparison of measured precipitation, discharge (Aguima) and soil moisture (savannah site).

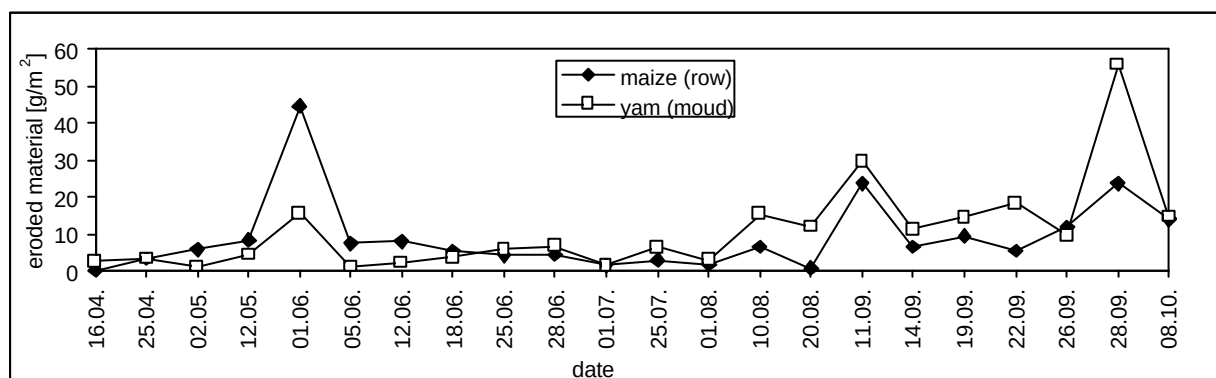


Fig. A2-3: Soil erosion of maize and yam, measured by sediment traps.

Hydrogeology and groundwater chemistry

The aquifer of the Aguima catchment is located within the migmatitic basement which consists of fractured rocks. The main fractures (NW-SE and SW-NE direction) represent the drain system of the groundwater which is captured in the two wells of the village Doguè.

The groundwater recharge process strongly depends on the composition of the lateritic weathering zone. Lateritic strengthened soil horizons may act as aquitards. The percolating water is then dammed up and forms interflow (depending on the slope conditions). If there are preferential flow paths in these aquitards, the water partly contributes to groundwater recharge. As the aquitards do not cover the catchment as a whole, a direct percolation from the soil water zone to the groundwater is partly present. The origin and the age of water can be derived from the chemical composition of the water. Groundwater, soil water and surface

water in the catchment differ significantly concerning their chemical composition (Fig. A2-4). Depending on the storage time and aquifer mineralogy groundwater shows a higher mineral content. The soil water shows increased K and Ca concentrations, the surface water increased Fe, Na and Ca concentrations. To identify the flowpaths tracer tests will be carried out.

Local and regional water balances – hydrological modelling – Hydro-GIS:

Based on the measurements of the first rainy season water balance terms at the local scale can be compared to regional water balance terms. At the savannah climate station near Doguè in 2001 an annual precipitation sum of about 800mm was measured. The runoff contribution of four small sub-catchments of the Aguiama (3-17 km²) was between 23 and 136 mm/a, depending on soil and vegetation conditions. Thus as expected the catchment contributions to runoff at the local scale show a high variability but average to values comparable to regional scale values which can be seen by extrapolating the regression curve of the gauge station Térrou-Wanou (fig. A2-5) to lower rainfall.

For the hydrological modelling at the regional scale parameterisation rules developed at the local scale and a spatial data base (Hydro-GIS) are required. For the Térrou basin which is a subbasin of the upper Ouémé valley following data were made digitally available:

- ?? Digital soil map 1:200.000,
- ?? Digital geological map 1:200.000,
- ?? Digital elevation model (100m spatial resolution), derived from contour lines of the topographic map 1:200.000,
- ?? USGS land use classification (1 km spatial resolution),

First regional simulation (parameters derived from Hydro-GIS and literature) have been performed for the Térrou basin. The TOPLATS approach has been chosen as TOPLATS is already used as land surface scheme within the atmospheric model LM in IMPETUS. Since the parameterisation rules are still under development, the modelled discharge does not fit exactly the measured hydrographs.

References:

Famiglietti, J.S. & Wood, E..F. (1994): Multiscale modelling of spatially variable water and energy balance processes. Wat. Res. Res. 30/11, 3061-3078.

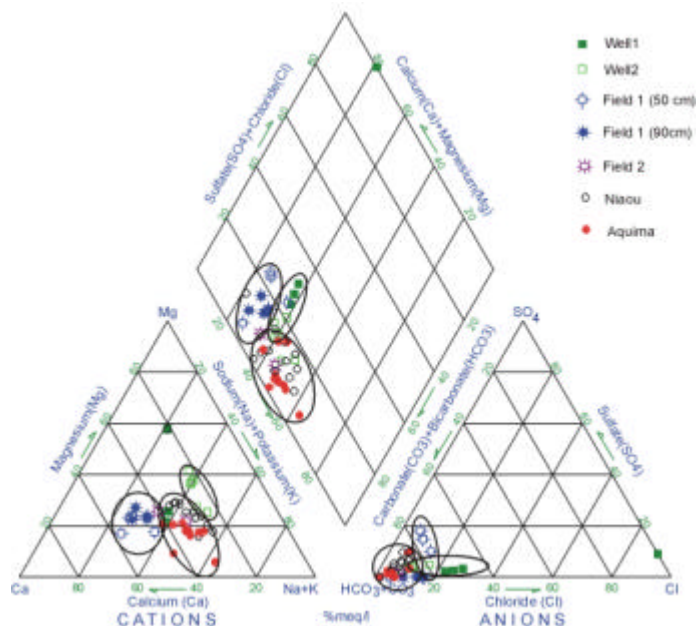


Fig. A2-4: PIPER diagram of water samples - Aguiama catchment and village Doguè.

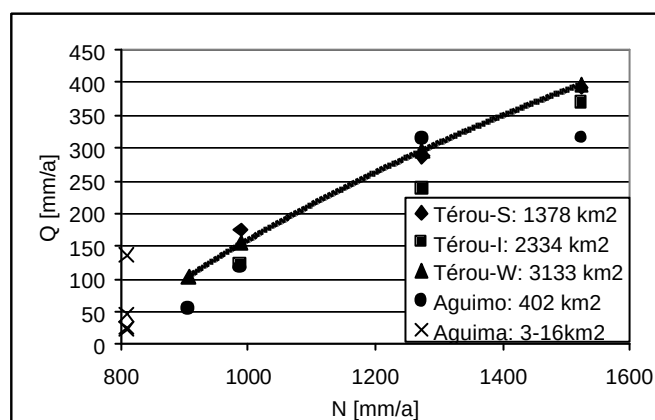


Fig.A2-5: Annual precipitation (station Doguè) versus discharge of four rivers in the upper Ouémé valley (1997-2000). Black line: logarithmic regression of the gauge Térrou-Wanou.

Subproject A3

FUNCTIONAL RELATIONSHIPS BETWEEN SPATIO-TEMPORAL VEGETATION DYNAMICS AND WATER CYCLE

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Key words: West-Africa, land use cover change, vegetation dynamics, remote sensing, water use efficiency, biomass, transpiration, regeneration potential

Abstract:

The IMPETUS subproject A3 employs a multidisciplinary approach to investigate the functional relationships between spatio-temporal vegetation dynamics and the hydrologic cycle in the Upper Ouémé catchment in central Benin. Vegetation within the catchment was assessed using remotely sensed data and processing. The hydrologic cycle and biomass production parameters of transpiration and radiation budget were measured in situ on several measurement stations and interpolated to wider areas. The vegetation dynamic was then analysed at time scales of a phenologic cycle as well in decades in detail on 39 field test plots and through remote sensing for the entire catchment. Dramatic land use and land cover changes were assessed within the study area for the last 20 years, and land cover change “hot spots” were identified. Based on this analysis, and in co-operation with other IMPETUS sub-projects, it is possible to derive a land use change model which provides additional knowledge for important land use change factors, including socio-economic data. Interactions between the different vegetation types present within the study area and the hydrological cycle are fundamental to developing an appropriate hydrologic and development management system for the region. Additional investigations focused on the regeneration potential of forest areas following logging as well as on methods to increase agricultural water use efficiency are other important components in such a management system. Within Sub Project A3, new techniques and methods for a scientific approach to a rapidly changing semi-humid tropical environment were designed. The subproject is well integrated in the IMPETUS project, as well as with other international research groups and programs. These include the NASA’s Land Use and Cover Change (LUCC), the International Geosphere Biosphere Programme (IGBP), IITA, GTZ, BIOTA and DANIDAT).

Goals:

The existing land use and land cover of an area is a key parameter within the hydrological cycle. In the IMPETUS project, the main goal of Subproject A3 is to investigate the functional relationship between the vegetation cover and water cycle using a process-orientated approach. Vegetation has high temporal and spatial dynamics in the study area, principally due to human impact and to the differing moisture regimes of the dry and wet seasons in the semi humid tropics. As an important step towards an integrated management system, it is necessary to assess these dynamics and understand their impacts on the hydrological cycle.

Research design and results:

In spite of organisation problems faced when working in a developing country, we have established a research program in the study area and have made significant progress to date.

Vegetation assessment

Development of vegetation test plots: The Upper Ouémé region is a part of the transition zone between the Northern Guinea Zone and the Southern Sudanian Zone. The natural vegetation in the area is characterised by tree- and scrub-savanna, with a high grass understory. As a part of this study, botanists have established 39 test sites, 30 m x 30 m in size, in the catchment area to assess the flora and to record relevant vegetation parameters, including basal area, height, leaf area index, biomass and many others. Large-scale vegetation dynamics are regularly monitored in these test sites. In order to assess the impact of logging on the area's micro climate and the regeneration of forest, 72 transects, 5 m x 15 m in size, were established and each was equipped with a micro data logger. Local participants were recruited and trained in order to monitor each plot throughout the year. All information acquired from the test sites is assembled in a spatially related database, allowing ready access to the data by other members of the group.

Assessment of the actual land use / land cover with remote sensing: The Remote Sensing Research Group has the task of assessing the land use and land cover for the Ouémé catchment. This was done by classifying 30 m x 30 m LANDSAT ETM 7 satellite images. Employing optical sensors in a semi humid area is complicated by the presence of the dust and moisture typically present in the atmosphere. These conditions required intensive pre-processing of the LANDSAT image data. Advanced radiometric correction of the images was performed using the program STEAMER and meteorological reanalyses data as input. Additionally, the program ATCOR was used. A land cover classification system was developed in collaboration with the botanists and the meteorologists to meet the requirements of both groups. A sound basis for the classification system was established through an intensive field campaign to collect *in situ* vegetation data. In co-operation with GEOSYSTEMS, Inc. new tools for linking remote sensing images with GPS measurements were successfully developed and tested (THAMM & SCHMIDT, 2001). This effort led to significant time savings and increased efficiency in field data gathering. As a final component of the field campaign, a comprehensive field database including digital photographs of more than 600 training areas was also compiled. The classification of remote sensing imagery to assess vegetation in the semi-humid tropics is a demanding task, principally due to the high inter-seasonal variability of the vegetation. Conventional classification methods based on spectral properties have their limitations in capturing this response variability. To solve this problem, a new knowledge based classification method utilising a multitemporal image set was developed and employed successfully (SCHÖTTKER & THAMM, 2001). This approach resulted in a 15 % increase in accuracy for classification of vegetation types which are subject to brush fire. Only very coarse resolution digital elevation models are available for the Ouémé catchment area of investigation. Data from the recently orbited ASTER satellite were used in combination with highly precise differential GPS measurements (DGPS) to produce a 30 m x 30 m resolution digital elevation model for the test area which we refer to as the "super test site". This study also had the goal of calculating leaf area indexes for the different vegetation types present within the study area. To complete this task, a number of *in situ* measurements were made and compared with similar values derived from satellite images.

Assessment of the relevant physiognomic and meteorological properties of the vegetation: The agriculture group determined transpiration rates, biomass and water use efficiency for the different vegetation units. This effort included working closely with local farmers in the test site. 150 individual fields were selected and cultivated with different crops (sorghum, cotton, maize, yams, peanuts). The biomass production and nutrient fluxes in relation to the water

demand were determined for each field. Additional transpiration measurements were acquired through the use of a new instrument developed by Burkhardt, Inc. (Burkhardt et al., 1999; Burkhardt and Gerchau, 1994). These transpiration rate data were compared with transpiration rates derived from different methods including sap flow measurements and approaches using meteorological measurements. Two micrometeorological stations were installed in the study area to record the complete energy balance.

Vegetation dynamics

Assessment of the vegetation dynamics: Vegetation has different temporal dynamics: the inner-annual vegetation dynamic within the phenological cycle and the long-term vegetation dynamic caused by human or environmental factors such as long term climatic change.

Assessment of the inner-annual vegetation dynamic: The four LANDSAT ETM images which were acquired for this study show clearly the different stages of development within the vegetation phenological cycle and were used to conduct an investigation of the inner-annual vegetation dynamic in the study area. Fire within the study area is of great significance to the inner-annual vegetation dynamic: more than 40 % of the area in the Upper Ouémé catchment is subject to burning. That is also an important factor concerning the overall carbon budget within the study area. The timing of the bush fires is also significant in the land use management concept for the area. Typically, fires are started by farmers at the end of the dry season, thus plant and soil nutrients will be washed out with the first rain. Early fires are not likely to go out of control and provide more time for the nutrients to penetrate the soil. We feel that information available from the new MODIS satellite will allow us to detect fires within the study area with even more precision. NOAA Advanced Very High Resolution Radiometer (AVHRR) images were also analysed in addition to the LANDSAT ETM scenes. When compared with the ETM data (with their relatively fine spatial resolution), AVHRR imagery has a much more coarse spatial resolution (1000 m x 1000 m) but a much finer temporal resolution with daily image acquisition. Vegetation information derived from the AVHRR data is valuable as input for meteorological models or to verify the model results. Information derived from these remote sensing inputs over the entire Ouémé catchment is then compared with field test plot information generated by the botanists along with the micrometeorological spot measurements performed by agronomists, following interpolation of the field test plot data and point source meteorological data to greater spatial units.

Assessment of the long-term vegetation dynamics: The long-term vegetation dynamic within the study area was derived through analysis of historical LANDSAT TM imagery acquired during the 1980's and comparison of these data with existing vegetation cover. Three different change detection methods were employed: Principal Component method (PC), change vector analysis and post classification method. The land use and land cover of some portions of the Upper Ouémé were subject to significant changes between the 1980 and 2000. In the "Forêt de l'Ouémé" area, approximately 15 % of the area changed from forest to field and settlements. The main settlement lines are along the roads; examples include the road between Ndali and Djougoum and the road between Woubéro and Bassila, both of which were enlarged during the early 1990's. Settlement in these areas is extremely dynamic and land use and cover change is quite rapid; our research indicates that more than 10 new settlements were present just in the one year period between 1999 and 2000. In addition to the settlement with areas of natural vegetation cover, commercial logging is a significant environmental problem in the area of investigation. Four timber species (*Khaya senegalensis*, *Azelia africana*, *Isobertina doka*, *Pterocarpus erinaceus*) are subject to large-scale logging. Botanists have recorded more than 350 cut down trees (through count of remaining tree trunks) in an area of only 5 km x 2 km within a year. Urban settlements have also expanded between the 1980's and 2000. Both major cities within the test site, Parakou and Djougou, as well as smaller towns like Bassila, have increased their area by nearly 50 %. Information

regarding land use and land cover in the area change were combined with the socio-economic data collected from the IMPETUS subproject A4. These data include precise demographic data for every village and new settlement along Woubéro-Bassila road. This data set is very useful for the developing of a land use and land cover change model for the region and for estimating future urban land area demands for in the area.

Establishing an integrated land use management system will also allow the preservation of critical areas within the region by identifying such land cover units as forest sanctuaries. Analysis of remote sensing data shows clearly that human development and urban expansion stop precisely at the boundaries of the sanctuaries. This phenomenon is observed at the northern boarder of the “Forêt de l’Ouémé”. In addition, areas where the borders of the sanctuaries are being violated can be readily identified using satellite imagery, and sanctions may then be put into effect. The 1980 and 2000 land use classifications can also be used as inputs for climate and hydrologic models to more accurately estimate the impact that changes in land use and land cover may have on the hydrological cycle.

Activities towards a management concept

In addition to the important research activities to estimate the influence of land use change on the hydrological cycle described above, additional activities are ongoing which focus on developing and implementing a scientific system of regional land use management.

Increasing crop water use efficiency: Colonisation is closely related to the efficiency of agriculture in the region. If yields per hectare can be increased, less new area has to be colonised. Agronomists are currently investigating the impacts of different fertilizer types on the yield on their 150 test fields in the study area. Of special interest is the use of organic fertilizers which are meant to improve the water holding capacity of soils.

Estimating the regeneration potential of forests: Botanists are investigating the mechanism of forest regeneration following logging. By analysing changes in micro climate in logged forest clearings and by performing seeding probes, estimates may be made regarding which types of trees regenerate in which size of forest clearing. This aids in accurately estimate the size of forest patches which must be preserved for regeneration of selected tree species.

Implementation of a land use and land cover change model: A land use and land cover change model can be developed which describes the process of land use and land cover change and may be used to predict future changes in the region. This model is based upon the land use and land cover changes detected with remote sensing along with the socio-economic data generated by IMPETUS Sub Project A4. This model will be of particular use in estimating land use and land cover changes which may be induced by development projects such a building a new road or expanding and existing road. In addition, significant land use and land cover change “hot spots” can be defined within the region.

References:

- Burkhardt J., Gerchau, J. (1994): A new device for the study of water vapour condensation and gaseous deposition to plant surfaces and particle samples. *Atmospheric Environment* 28, 2012-17.
- Burkhardt J., et al (1999): Measurements of electrical leaf surface conductance reveal re-condensation of transpired water vapour on leaf surfaces. *Plant, Cell and Environment*, 22, 189-196.
- Schöttker, B. & H.-P. Thamm (2001): Wissensbasierte Landnutzungsklassifizierung in Benin (West Afrika) unter Verwendung des IMAGINE Expert Classifier™. *Proceedings of: Geosystems user Group meeting 2001, Germering, Germany*
- Thamm, H.-P., Schmidt, M., Mévo Guézo, C. & G. Menz (2000): An integrative management project for efficient and sustainable use of fresh water in western Africa (IMPETUS), *Proceedings of the 1 st EARSel Workshop on Remote Sensing in Developing Countries. Gent, Belgium.*
- Thamm, H.-P. & Schmidt, M. (2001): Erhebung von Ground Truth mit dem GPS Link von ERDAS IMAGINE für eine Klassifizierung der Landnutzung in Benin und Marokko im Rahmen des IMPETUS Projekts. *Proceedings of: Geosystems user Group meeting 2001, D-Germering.*

Subproject A4

SOCIO-DEMOGRAPHIC DEVELOPMENT AND MIGRATION AGAINST THE BACKGROUND OF RESOURCE SCARCITY

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Key words: Water supply, population growth, development strategy, resource availability, migration, settlement; land-use-systems, modelling, supply and demand functions

Abstract:

The main objective of various research activities in this subproject is to analyse the interdependencies between resource availability and socio-economic respectively demographic development in selected places in Benin.

Because of completely lacking or incomplete time series of secondary data the investigation is partly based on empirical social research. Most of the work packages still remain in the phase of data collection and of preliminary evaluation. The status of preparing the necessary data-set and developing conceptional framework is still different because of manifold problems including recruiting scientific staff or restrictions in working conditions.

Due to the actual findings, it is obvious that Benin at all does not belong to those countries with poor water supply. It is most of all a problem of an urban-rural-dualism in water availability related to different water-access and use. In those places with water-scarcity or water insecurity this is the problem of highest priority for the population.

As far as development strategies and related institutions are dealing with the improvement of resource availability it seems to be that the approaches do not meet the need of the population.

In the field of migration it is quite clear that the settlement takes place in an institutional vacuum and without governmental support. The consequences are transformations of socio-economic structures on local level and changes in land use patterns, caused by migration as well as by significant political problems in managing property rights.

Finally collecting of data on natural indicators related to land use systems show very different regional conditions. According to the efficiency of water application and capacity of soils in CO₂-storage the expansion of agricultural production is different.

Results:

The investigation on water supply, which started in 2000 is mostly based on an interdisciplinary analysis of selected private households at different places. In view of the fact that Benin shows a supply of renewed sweet water of 4.800 cubic metres per capita and per year it is not a water poor country exceeding significantly the limit of 1.001 to 1.666 cubic metres for water scarcity. Problems in water availability mostly are obvious on regional and local level. In this context the differences in water consumption between urban and rural areas show a clear picture. During the rainy season the average water use per capita and per day is

18,9 liters compared to urban inhabitants with 28,7 litres. The range of consumption per capita is extended in urban households up to 69,9 litres, because of access to different sources in water supply. In villages, the distribution of water consumption is nearly equal caused by identical living conditions. For example, there is no possibility to buy water in dry seasons, if the own well dries up.

Water scarcity is a problem of very high importance if households mention their environmental risks. Related to their personal situation in daily life, the aspect of water supply only ranks on fourth position beside lack of money, disease and poverty. In spite of temporary water-insecurity this is no reason for migration, which obviously is due to private property of house and cultivated area. Beyond this, it is a seasonal phenomenon for which solutions should be available. In general the majority of the population included in the investigation points to the fact that there are no indications for water conflicts.

Less encouraging are the results of the effects of development strategies including the efficiency of related institutions. Based on a cross-section- and an in-depth-analysis the research activities on one hand were aimed at the identification of organisations supporting agricultural development and introducing micro-credit-schemes as well as being engaged in the process of decentralisation. On the other hand the analysis intended to describe and to evaluate different methods concerning for example the analysis of problems, targeted intervention to certain groups of population or to selected regions. On this background, the concatenation of actions and their effects is a very important aspect, which will result in development-orientated profiles of villages. The result of investigating 41 national and international organisations indicate that they hardly affect the agricultural sector in spite of the fact that this sector mostly influences natural resources.

A more differentiated judgement presents the following findings:

- ?? The establishment of micro-credit-schemes did not include poor people, which are not organised, but are in need of external support.
- ?? The co-operation with people migrating from outside did not work, because they only stayed for a limited time, which made it impossible to integrate these people into society.
- ?? Women have been a preferred group as beneficiaries of micro-credit-schemes because they have a higher saving quota and thus, the ability to pay the credit back.

In the same way the results of the evaluation of projects in 5 villages and of 2 infrastructure programmes show that its effects on food production respectively on income generating were limited. Most of all migrating people could not profit from these activities as shown above.

Concerning the aspect of migration in a narrower sense and the dynamics of settlement it is important to know the new social background created by migrants, their forms of political organisation and integration as well as their impact on the transformation of the traditional systems. The results present a sobering picture insofar as the process of decision making within separated groups of migrants is informal and characterised by anarchic structures. On the background of a keen competition on the control of new institutions on village level there are winners and losers of social change leading to significant shifts of the traditional structure of power.

Beyond this the investigation shows that – caused by migration – land-use-patterns change and that new forms of cultivation are introduced. These results will be important for the next step of research, when the interdisciplinary modelling will take into account changes in surface covering and the process of deforestation.

Analysing the problem of property rights, the conclusion is obvious that migrating farmers are confronted with local owners. The traditional legislation on property does not give any legal protection to the newcomers, which again affects the utilisation of natural resources. So, for

example, the prohibition of investment in tree planting will prevent reforestation of cleared areas.

Summarising the development, the results indicate that conflicts on property rights will increase – a challenge which is to be managed by reforms of political structures on local level.

Concerning the influence of land use systems on organic matter dynamics and on water use efficiency, the following approaches and results are interesting:

With the demographic pressure on the land, the farmers who still have enough land to clear, maintain or increase their level of production through the extension of the agricultural area whereas those who do not it reduce the duration of the fallow. That involves a fall of the biomass production and consequently a low content of soil organic matter. According to the importance of water and the organic matter in the agricultural production, this study analyses the influence of the land use systems on the organic matter dynamic and the water use efficiency.

After the quantitative data collections and analyse, the villages of Doguè and Sérou were selected respectively, as representing the villages which have still land to clear and those which do not have it. The land use in each village has been divided into four land use systems: forests, fallows, cashew plantations and other crops areas (cassava, yam, maize, sorghum, rice, beans, groundnut, cotton, ...). Observations and quantitative data gathering began in June 2001. Parameters include litter fall, organic matter, height of the crops/trees, leaf area, biomass production, soil water, soil CO₂ emission...etc and are taken within sixty four samples whose dimensions of each one are 30m*30m.

Concerning the organic matter dynamics and the carbon sequestration, the preliminary results show that the biomass production during the farming season (June –November) 2001 is higher in the samples of the crops area in Doguè (5.2T/ha) and Sérou (5.0T/ha) than it is in any other land use system. If one considers the biomass production of each land use system during all 12 months, it is probable that the food crops provide less litter. Whereas the majority of the food crops produce their biomass between June and November, the cashew plantations and the forests continue to provide litter especially in dry season. The forest of Sérou comes in 2nd place with a litter production from 2.3T/ha. The Cashew plantations in Doguè and Sérou produced respectively 0,4 and 1,1T/ha litter. The forest of Sérou (with 6,2T/ha soil litter) as well as the cashew plantations in Doguè (3.5 T/ha) and Sérou (4.9T/ha) can be defined as CO₂ sink. Whereas in the other samples (forest of Doguè, fallows), bush fires and the burning of the harvest residues destroy all the litter and recycle the carbon in the form of gases (CO₂, CO.) in the air, the areas of cashew as well as the forest of Sérou are carefully protected against the fire. The CO₂ emission from the soil under different land use systems was higher in rain season and between 0.6 and 1.8 g/m²-h.

The water use efficiency in the different land use systems in Sérou, is summarised in the table below.

Water use efficiency under different land use systems in Sérou:

Land use system	Biomass production (Kg/m ³)			Calories production (Kcal/m ³)	
Other crops area	0,551			357,0	
Cashew	0,131	Tubers	0,542	Tubers	301,2
Fallow	0,028	Leguminous	0,450	Leguminous	287,8
Forest	0,260	Cereals	0,661	Cereals	482,1

Supposing that 2000 Kcal are the daily needs of each person in Sérou, and that 75% (1500 Kcal) of calories come from the production of tubers, leguminous plants and of cereals, 4,2m³ water are currently necessary to produce the 1500 Kcal (1533,6m³ as annual water requirement per capita in Sérou).

A final approach is dealing with the analysis of long-term perspectives of economic, social and demographic development under alternative scenarios of resource availability and socio-economic framework conditions by calculations on simulation basis. The main methodical tool is the programming of a recursive-dynamic model of the agricultural sector.

The model is still in preparation and the necessary data adequate to the model are collected respectively, they will be provided by national and international organisations

References:

- Adanguidi, J.: Réseaux, marchés et courtage : la {filière igname au Bénin (1990 - 1997)} /. Münster; Hamburg: Lit, 2001. - XXIII, 301 S. : graph. Darst., Kt.; (franz.) (Mainzer Beiträge zur Afrika-Forschung ; Bd. 7), Zugl.: Hohenheim, Univ., Diss., 2000
- Adjovi, N. Ahoyo: Analyse des déterminants de la pauvreté en milieu rural (=Cellule d'Analyse de Politique Economique (CAPE); Cotonou 2000
- Alimi, M.R.; Faaki, V.: Rapport d'études sur la gestion alternative des conflits les aux ressources naturelles: Cas de république du Bénin. ,O 1998
- Assad, M. et al.: Management of water resources, Herausgeber: Weltbank; Washington 1999
- Ehlers, W.: Wasser in Boden und Pflanzen. Dynamik des Wasserhaushaltes als Grundlage von Pflanzenwachstum und Ertrag; Göttingen 1996
- FAO: Atlas of water resources and irrigation in Africa; Rome 2001
- Floquet, A.: Dynamique de l'intensification des exploitations au sud du Bénin et innovations endogènes. Un défi pour la recherche agronomique; Hohenheim 1993
- Floquet, A.; Mongbo, R.: Des paysans en mal d'alternances; Markgraf Verlag, Weikersheim 1998.
- Nye, P.H. ; Greenland, D.J.: The soil under Shifting cultivation. Technical communication, 51. Commonwealth Bureau of Soils; Harpenden 1960.
- OECD: Water consumption and sustainable water resources management; Paris 1999
- Roesch, M.: Surplus agricole e stratégies de production chez les exploitants agricoles de la province du Zou, Bénin. Thèse de Doctorat. Université de Montpellier 1992
- Senahoun, J.: Programmes d'ajustement structurel, sécurité alimentaire et durabilité agricole : une approche d'analyse intégrée, appliquée au {Bénin} /. - Frankfurt am Main ; Berlin ; Bern ; Bruxelles ; New York ;Lang, 2001. - XVII, 189 S. : graph. Darst.; (franz.) (Development economics and policy ; Vol. 18), Zugl.: Hohenheim, Univ., Diss., 2000
- Schlesinger, W.H.: Carbon sequestration in soils: some cautions amidst optimism. Agriculture, Ecosystems and Environment 82 (2000) 121-127
- Tchégnon, Ph.; Biaou, G.: Migrations rurales, systèmes d'exploitation agricole et gestion des ressources naturelles: cas de la sous-prefecture de Savè. In: Communication aux premières journées scientifique sur l'agriculture durable du SNRA: INRAB/UNB/CBRST; Cotonou 17-18 Août 1995.
- UNESCO (Herausgeber): Guide lines for conducting water resources assessment; Paris 1998
- van den Akker, E.: Makroökonomische Bewertung der Auswirkungen von technischen und institutionellen Innovationen in der Landwirtschaft in Benin; Beuren, Stuttgart: Grauer, 2000. - XVI, 322 S. : graph. Darst., Kt.; Zugl.: Hohenheim, Univ., Diss., 2000
- Weisshaupt, Gerhard: Vom Wasserloch zum Dorfbrunnen, Erfahrungen aus 30 Jahren Brunnenbau in Benin; Bad Honnef 2002
- Weltbank (Herausgeber): A guide to the formulation of water resources strategy; Washington 1994
- WHO: Financial management of water supply and sanitation; Geneva 1994
- WHO: Global water supply and sanitation assessment: 2000 Report; Geneva 2000

Subproject A5

RISK AND INSECURITY WHEN RESOURCES ARE SCARCE: ETHNOLOGICAL AND MEDICAL PERSPECTIVES ON THE AVAILABILITY, QUALITY AND MANAGEMENT OF WATER

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Key words: Risk theories, indigenous medicine, waterborne diseases

Abstract:

The aim of the project is the assessment of risks caused by complex water problems in Benin. In this interdisciplinary approach anthropological and medical sciences (bacteriology and virology) are collaborating. Modern risk theories provide a basis for the holistic analysis. Main issues are the detection of communal "hazards" influencing the water system with respect to quantity and quality, the local perceptions of these dangers and the role of local risk minimising strategies. Due to the long term characteristics of anthropological studies and the establishment of required settings in the medical part (laboratory construction, method validation) only preliminary results have been obtained from 3 out of 5 work packages. Malaria, respiratory and gastrointestinal infections are the leading diseases on the single village level, highlighting hookworms as predominant parasites. Although no significant differences could be observed, more infections have been seen in well- than in surface-water dependant collectives. Daily water consumption was approximate 17 litre per inhabitant. So far over 60 water samples have been taken out of 900 mapped locations (well and surface waters). First line analysis showed approximately 1300 isolates of bacterial species, requiring further differentiation and epidemiological judging.

Background:

The availability and quality of drinking water is crucial for the inhabitants of the West African Sahel and Sudan zones. Through their direct influence on agricultural productivity and health both factors have an impact on settlement and mobility patterns. In addition they determine the local strategies of resource exploitation and the epidemiology of the whole region. As a consequence of the decreasing water resources, the growing population and the burden of endemic infectious diseases tropical countries like Benin face this situation in a more extreme sense. Conflicts begin to raise on a local level concerning the use and the distribution of limited resources, spreading eventually even to the developed part of the world. Therefore the conception and evaluation of risk minimising strategies is decisive from a local, regional and global point of view.

Objectives:

The subproject A5 of IMPETUS combines the disciplines of anthropology and medicine representing the idea that only a holistic analysis of water problems meets the requirements

for efficient management strategies. The common basis for both sciences is provided by modern risk theories. Main issues are the detection of communal "hazards" influencing the water system with respect to quantity and quality, the local perceptions of these dangers and the role of local risk minimising strategies. Five work packages have been created to cover these problems:

The work package "Management of water and of water-dependant resources in local, social and political settings of the upper Ouémé region" deals with the interaction between economy, migration and conflicts on a regional scale. This investigation focuses on the documentation and comparative analysis of economically, culturally and historically differing concepts of water use.

In the work package "Water households economy in the upper Ouémé basin" social and economic strategies are analysed on a local (village) level. Surveys and interviews are used to evaluate the agricultural production as well as consumption patterns with special attention to social inequality and changing owner rights.

The work package "Water and health conditions: indigenous medicines in the Haute Vallée de l' Ouémé" assembles different perceptions and practices related to water dependant sickness. Local disease and health concepts as well as preventive and curative measures are analysed by interviews and participating observations.

The work package "Water and infection: quality of drinking water and epidemiology of water associated infectious diseases in the Ouémé-Region" includes the detection, characterisation and quantification of water-transmitted bacteria with respect to WHO advice.

In the work package "Proof of viral indicators in various sources of drinking water in the upper Ouémé basin" the risk of virally contaminated water is investigated. By testing virological indicators (Enteroviruses, Norwalk-Viruses and Hepatitis E Virus) the effect of these agents on local epidemiology is assessed.

Results:

Due to the special character of the anthropological studies with long-term field campaigns and the establishment of required settings (laboratory construction, method validation) actually only preliminary results and observations exist. As a consequence the inherent medically orientated work packages are presented exclusively in the following.

Water and health conditions: Indigenous medicines in the "Haute Vallée de l' Ouémé"

Research has been carried out for more than twelve months in Dendougou, a small village of about 500 inhabitants in the north-east of Djougou. Basic indicators of the local situation were gained by a micro-census. People living in Dendougou belong to 12 different ethnic groups, predominately Yom (36,5 %), Cocoma (18,7%) and Fulbe (17 %). All other ethnic groups are below 10 %. 52 % of the married population is living monogamous versus 48 % polygamous respectively. Only 21 % of the population older than 6 years had a formalized education (7 % went to primary school, 2 % to a koranic school, 12% learned to read and write in a campaign fighting illiteracy). 60 % of the villagers are Moslems, 4 % are Christians and 1 % rely on Fetishism, but 35 % practice no religion at all. Interestingly most of the Moslem, Christian and Atheist families possess a family fetish (60% of all families). There are three different resources of water in Dendougou: Well water, rainwater and water of rivers or waterholes. 16 % of all families rely entirely on surface water resources during the dry and rainy season.

Based on this descriptive data, three long-time studies have been effectuated in the second half of 2001:

From Autumn 2001 to January 2002 a longitudinal health survey in eight selected families has been undertaken, thus covering one rainy as well as one dry season. Families with access to well water were included in addition to families which entirely rely on water from the river or

water holes. First analysis showed malaria, fatigue and fever associated illnesses as leading diseases, followed by respiratory and gastrointestinal infections. Interestingly no significant difference between the well- and the surface-dependant groups could be detected, suggesting equal water qualities. Never the less observations showed slightly more infections among people using well water resources.

A second longitudinal health survey focused on the examination of blood and stool samples of the indigenous population, which were analysed twice monthly at a laboratory in Djougou. The tests were concentrated on malaria and intestinal parasites, showing that 55 up to 73 % of the population had actual manifestations or at least former contact. Under 47 infected people 32 cases (72 %) were due to *Necator americanus* (the sub-Saharan variant of *Ancylostoma duodenale*), which causes intestinal infection. These hookworms both infect man by penetrating the intact skin, usually of the feet. The absence of latrines and the lack of shoes were suggested as main factors favouring this route of transmission. Again there were little more infections in the well related group.

The third study concentrated on the consumption patterns of water in the local setting of Dendougou. It was effectuated in close co-operation with the subprojects A4-1 and A5-2, thus allowing a comparison of different rural and urban settings (precisely the villages Bougou, Dendougou, Pélébina, Sérrou and the town of Djougou). The daily water consumption in Dendougou was approximate 17 (range 15 - 20) litres per inhabitant.

More complex analysis of the collected data has to be done to identify the main influencing factors, including the influences of indigenous medical specialists on health concepts and disease models in different ethnic and gender groups.

Waterborne pathogens in the upper Ouémé-region

Due to a restricted infrastructure especially in the countryside of Benin a stationary laboratory and a mobile unit for the collection and transport of water samples had to be established on the ground of the *Service Régional de l'Hydraulique* in Parakou before starting the analysis. In addition more than 900 easy accessible watering places (wells and surface water) in the area between Parakou, Djougou and Bassila have been mapped and transferred into a special database. These locations will serve as primary objects for taking the samples. Water-associated bacteria will be detected by cultivation on special media and differentiated by serological, biochemical or genetical methods, followed by investigation of resistance patterns. The analysis of virological indicators (Enteroviruses, Norwalk-virus, Hepatitis E virus) combines the pre-analytical concentration of water samples in a transportable system with the detection of viruses and viral RNA by cell culture or polymerase chain reaction, respectively. For technical reasons some parts of this work has to be performed in the German laboratories of the project leaders, requiring airway transportation.

Following the successful custom agreement between Germany and Benin in August 2001, the establishment of the required settings as well as the validation of the laboratory methods have been finished by the end of the year 2001. Meanwhile (15.03.2002) more than 60 water samples have been taken from different locations in the catchment and analysis is still ongoing. First line analysis showed approximately 1300 isolates of bacterial species requiring further differentiation. The relevance of these results will be judged dependant on the local epidemiological situation. Data for this investigation will be collected by special questionnaires during the ethno-medical collaboration in the subproject A5. Furthermore results of the climate observation studies (subproject A1), hydrological and geological examinations (subproject A2), exploitation of the soil and dynamics of vegetation (subproject A3), as well as data on the regional development of the population (subproject A4) will be integrated in the epidemiological analysis.

PROJECT B

WATER-BALANCE OF THE DRÂA-CATCHMENT AREA AND SOCIO-ECONOMIC IMPLICATIONS

Subproject B1

SPATIAL AND TEMPORAL VARIABILITY OF PRECIPITATION

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Key words: Precipitation diagnosis, tropical-extratropical interactions, remote sensing, meteorological modelling, scale-interactions, land surface-atmosphere interactions

Abstract:

The principal goals of the meteorological subproject B1 consist of the determination of the atmospheric branch of the water budget for the Drâa catchment and the assessment of the mechanisms that control regional precipitation/evaporation variability. These objectives are pursued by a twofold strategy based upon diagnostic and model studies. Both large-scale and regional-scale influences on precipitation and evaporation are analysed for time-scales from decades to single events in order to obtain a picture of the physical mechanisms behind Moroccan precipitation generation and its spatial and temporal variability. It is shown that precipitation south of the Atlas is to an important part determined by interactions between extratropical and tropical synoptic systems. The latter are significantly influenced by Atlantic sea surface temperatures and the North Atlantic Oscillation teleconnection pattern. High resolution modelling of individual precipitation events gives further insight into the underlying mechanisms and provides an interface to the estimation of snow ablation in the High Atlas as an important freshwater source for the Drâa. Plant transpiration and soil moisture in the Drâa valley itself are decisive factors for freshwater loss due to evaporation and significantly influence regional near-ground atmospheric flow, which can even lead to modification of the isolated convective showers in the region. The results of the scale-comprehensive process analysis obtained in B1 will enter the assessment of potential effects on freshwater availability in the Drâa catchment by global and regional changes.

Results:

Diagnosis of mechanisms for precipitation variability in Morocco

Due to its geographical location between the North Atlantic storm track and the West African monsoon region, Morocco receives precipitation in connection with both extratropical and tropical regimes, which have been separately investigated. Extratropically induced precipitation, that is dominant in winter along the Atlantic coast, has been investigated by statistical analysis on a climatological basis. Mechanisms of tropically influenced precipitation have been studied with the help of case studies of rainy episodes in late summer/early autumn, when particularly the semi-arid to arid zones south of the Atlas mountains receive significant contributions to their annual rainfall amounts.

Winter time (DJF) precipitation in the north-western parts of Morocco shows a clear dependence on the position of the North Atlantic storm track. In months with large precipitation a southward to south-westward shift of the eastern end of the North Atlantic storm track is found, which is accompanied by an enlarged local cyclone and upper-level

trough activity north of Morocco and in the western Mediterranean. Baroclinicity is enhanced south of 45°N over the Atlantic in these situations. Corresponding westerly circulation weather types lead to an enhanced low-level moisture transport from the Atlantic into Morocco. Since sea level pressure is below normal west of the Iberian Peninsula in high precipitation months, a large negative correlation to the North Atlantic Oscillation (NAO) is found (for a schematic summary see Fig. B1-1a). Winter precipitation in north-east Morocco, north-west Algeria and south of the Atlas, however, appears to be stronger related to more localised cyclone activity. A strong low-level moisture transport from the Atlantic along the southern flank of the Atlas Mountains associated with cyclones west or north-west of Morocco can be identified as a decisive factor for precipitation south of the Atlas in winter. In contrast, north-east Morocco and north-west Algeria is dominated by the influence of cyclones in the western Mediterranean that are associated with enhanced baroclinicity over northern Africa and the Mediterranean and that lead to north-westerly moisture transports into this area.

The considered late summer/early autumn cases all reveal tropical-extratropical interactions (for a schematic picture see Fig. B1-1b). By trajectory analysis, tropical convection over Africa and the Atlantic – partly triggered by African Easterly Waves – could be identified as moisture sources for the rainy episodes. The moisture is transported northward, east of the axis of an upper-level subtropical trough, that extends anomalously deep into the tropics. The exact position and propagation direction of the trough, however, varies between the considered cases. In contrast to the extratropically induced precipitation regime, most moisture is transported at mid-levels, mostly above the dry Saharan planetary boundary layer. The moisture converges between 700 and 400 hPa over north-western Africa underneath a strong upper-level divergence centre, that is probably related to the advection of positive vorticity ahead of the trough. The resulting dynamically forced ascent, in connection with orographic lifting and surface heating, triggers convective rainfalls which occur preferably close to and downwind of the mountain chain. Precipitation intensities are mostly small to moderate, but some events of more than 20 mm in 12 hours were observed, particularly if the tropical air merges with an extratropical front over north-west Africa.

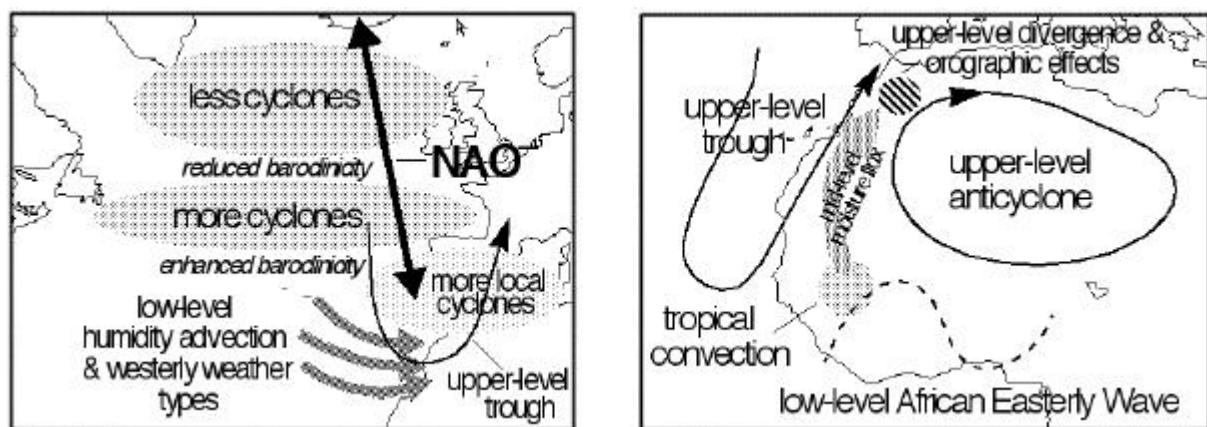


Fig. B1-1: Schematic overview of the principal mechanisms for precipitation generation in northwestern Africa: (a) extratropically induced rainfall (predominantly during the winter half-year) and (b) tropically induced rainfall (predominantly during late summer/early autumn). For details see explanations in the text.

Improvement of observational data by remote sensing

As in subproject A1, the lack of ground based rainfall observations, which are especially sparse south of the Atlas mountains, is sought to be overcome by the establishment of a satellite based rainfall monitoring system. The methodology is the same as in A1. In support

of identifying remote water vapour source regions for precipitation events in the Atlas region, satellite data are also used to derive the evaporation over the sea surface in the tropical Atlantic and the Mediterranean. The use of satellite data concentrates upon the derivation of the basic state variables wind speed, sea surface temperature, and near surface atmospheric specific humidity. Moreover, recently available TRMM satellite data allows for the first time estimates of evaporation from instrumentation on the same platform. Data from the Visible Infrared Scanner and the TRMM Microwave Imager have been used to derive monthly averages of the above mentioned basic state variables and evaporation. These new estimates were compared to older estimates from the HOAPS data set (Grassl et al., 2000). In spite of several differences, the HOAPS data set is fairly usable and biases can now be assessed using the new estimates from TRMM. At this stage of the project, a time series of 12 years (1987 – 1998) consisting of pentad and monthly averages on a $0.5^\circ \times 0.5^\circ$ spatial grid is available.

Results of model studies

Investigations with the global climate model ECHAM4 as part of the meteorological model chain within IMPETUS (cf. A1 for an overview) confirm the observational results depicted above with respect to influences of the NAO on Moroccan rainfall. In terms of sea surface temperature (SST), the North Atlantic subtropical and extratropical tripole in SST anomalies, which is itself linked to the NAO, plays a distinct role in Moroccan precipitation rather than the tropical teleconnections. Rising greenhouse gas (GHG) concentrations seem to cause decreasing rainfall amount over Northwest Africa which is likely to be connected with a positive trend in the NAO circulation mode (Paeth et al., 1999). However, the signal is weak and not consistent with all considered climate model versions.

As observations are especially sparse over Northwest Africa, the regional model REMO (cf. A1 for details) is run in a long term climate mode to supply a decadal rainfall climatology from 1991 onward to be used by all subprojects. Meanwhile, the rainfall climatology covers almost three years and is in excellent agreement with the CRU observation data (New et al., 2000). Future investigations will include a detailed analysis of the relevant synoptic processes and supply post-processed data sets of important atmospheric variables for all subprojects. Furthermore, it is intended to force REMO with ECHAM4 scenario simulations to obtain a valuable database for predicting vegetation changes (cf. B3) and socio-economic implications (cf. B4).

An improved understanding of mesoscale features of precipitation events in the vicinity of the Atlas Mountains is obtained by process studies with the *Lokalmodell* (LM) (cf. A1 for details). The synoptic scale forcing of cyclonic, frontal and mesoscale convective rainfall events was investigated in detail. The model simulates the interaction between tropical dynamics and midlatitude synoptic phenomena consistently with the observational results depicted above and gives further insight into the underlying mechanisms: For example, moisture convergence connected with extratropical fronts crossing the Atlas ridge, which leads to penetrating convection, usually causes rain only in the region north of the Atlas Mountains, unless there is a conveying of moist, tropical air from the south-east (see Fig. B1-2). At present, the capability of forecasting thunderstorms is enhanced by using remote sensing data (from radar network and TRMM satellite) to improve initial fields of cloud water.

In order to supply snow ablation modelling in the High Atlas mountains (cf. B2) with meteorological forcing by observational or LM data, a computationally inexpensive coupler has been designed, which interpolates atmospheric data to small scale hydrological grids and calculates surface energy and moisture fluxes (Born, 2001). The meteorological coupler is tested with IMPETUS climate station network data (cf. B2-2). As a first result, the influence of evaporation on snow ablation has been found to be on the order of magnitude of the snowmelt, which is much stronger than in mid-latitude alpine regions.

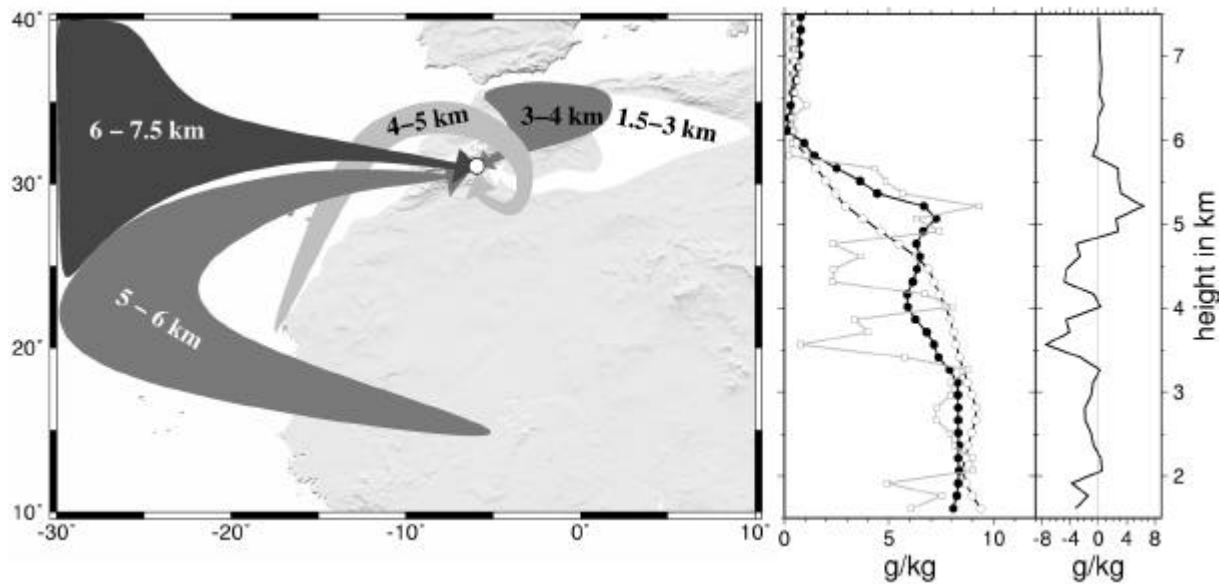


Fig. B1-2: The LM case study of a thunderstorm on Aug 25, 2001. Left panel: Conveyor belts with corresponding heights constructed from 84 h backward trajectories at 6°W, 31°N. Right panel: Profiles of specific humidity (i) thunderstorm (white circles), (ii) parcels on backward trajectories 6 hours before (black circles) and (iii) 60 hours before (squares, grey). Right part: differences between 60h backward trajectory-profiles and thunderstorm (curve iii minus curve i). This shows that the pre-storm moisture maximum in 5-6 km height is clearly of tropical origin.

Investigations with FOOT3DK (cf. A1) focus predominantly on evaporation in the mid and lower Drâa valley as an important sink for freshwater. For this purpose, FOOT3DK is nested into the Lokalmmodell (LM). The influence of a flood wave that leads to saturated soils in the Drâa oasis, the effect of transpiration of deep rooting plants and the benefit of improved soil masks on evaporation and the atmospheric circulation have been tested. The model reacts with pronounced sensitivity to all factors. In particular, soil moisture and transpiration changes exert a remarkable influence on the near-ground atmospheric flow that can even lead to changes in occurrence and efficiency of the isolated moist convective events in the region. The results underline the need for accurate surface and initial soil moisture data. The corresponding database is currently improved in subprojects B2 and B3. With accurate surface and soil data, FOOT3DK will be used as a viable tool to calculate area-covering fields of evaporation and related meteorological quantities on high resolutions up to a few 100 m. This information will contribute to an accurate determination of the water budget in the Drâa.

References

- Born, K., 2001: Coupling Meteorological and Hydrological Models: A Step towards Snowmelt Runoff Modelling in the High Atlas Mountains. Submitted to: Hydrological Processes.
- Grassl, H., V. Jost, J. Schulz, R. Kumar, P. Bauer, and P. Schlüssel (2000): The Hamburg ocean-atmosphere parameters and fluxes from satellite data (HOAPS): A climatological atlas of satellite-derived air-sea interaction parameters over the oceans. Max-Planck Report No. 312. Max-Planck Institute for Meteorology, Hamburg, Germany, 130 pp
- New, M.; Hulme, M. & Jones, P. (2000): Representing twentieth-century space-time variability. Part II: Development of 1901-1996 monthly grids of terrestrial surface climate. – *J. Climate* 13, 2217-2238.
- Paeth, H.; Hense, A.; Glowienka-Hense, R.; Voss, R. & Cubasch, U. (1999): The North Atlantic Oscillation as an indicator for greenhouse-gas induced regional climate change. – *Clim. Dyn.* 15, 953-960.

Subproject B2

WATER AVAILABILITY AND SOIL DEGRADATION

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Key words: climatology, soil water, snow cover, soil degradation, hydro-geology, hydro-chemistry

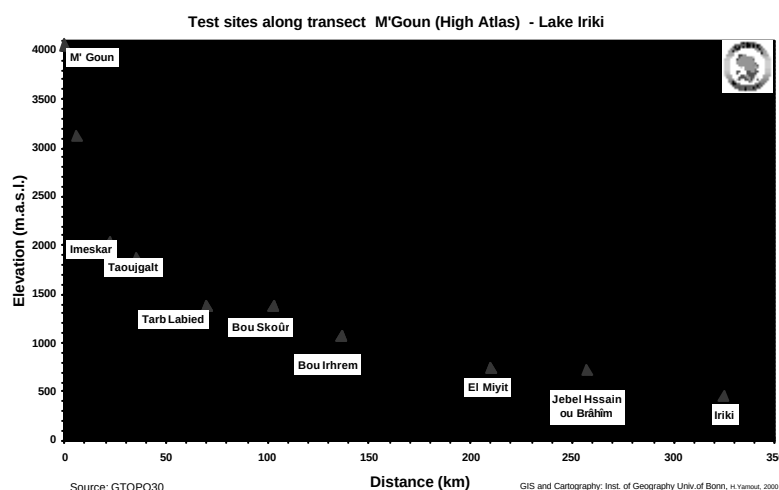
Abstract:

The aim of this project is to analyse and to quantify the climatological, hydrological, geological, and pedological processes in the investigated arid catchment. Eleven weather stations were installed at test sites situated along a gradient of aridity and elevation chosen in close co-operation with the subproject B3. Detailed small scale investigations were carried out at the test sites in order to gather process knowledge required for developing and applying hydrological simulation models. Small scale soil mapping is performed and soil degradation is monitored using erosion pins and sediment traps. The test site concept is the base for the regional characterisation of the whole catchment necessary for predicting the effect of global change on the hydrosphere.

In the High Atlas the spatial and temporal dynamic of the snow cover is investigated because it is the most important water resource for the reservoir at Ouarzazate and therefore for the middle Drâa catchment. The analysis is carried out by combining remote sensing techniques with field observations. Groundwater quality and quantity is monitored at numerous wells and springs. These data were combined with information about the isotopes ^{18}O und ^2H and detailed information concerning the geological structure to quantify the groundwater reservoir and their temporal dynamic.

Results:

For a detailed description of the weather at the test sites, eleven weather station were installed.



All stations were equipped with sensors for rainfall, temperature, relative humidity, radiation, wind velocity, soil matric potential blocks etc. Four stations were additionally equipped with TDR sensors to monitor the soil water content. Where possible discharge gauges were installed to measure runoff.

As an example for the analysis of the weather data obtained from the weather

Fig. B2-1: Position of the test sites and the weather stations along the gradient of elevation and aridity

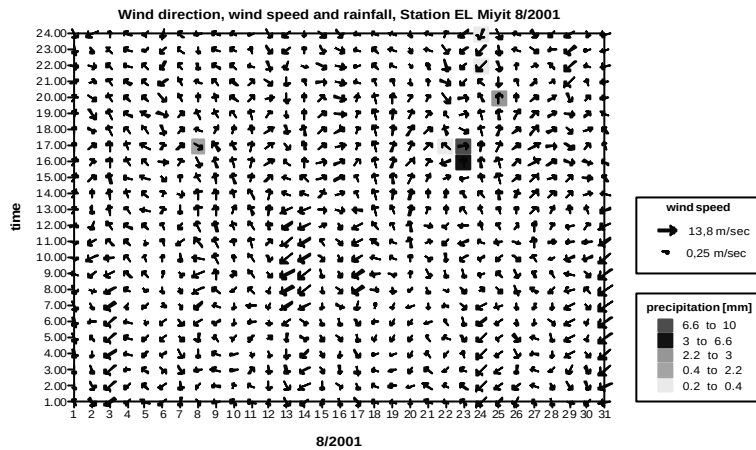


Fig. B2-2: Wind direction, wind speed and rainfall in El Miyit, August 2001

thunderstorm is apparent.

The determination of the water quantity stored in the snow cover at the regional scale can only be accomplished by using satellite images. As an example the calibrated and geo-referenced NOAA-AVHRR images were used for testing different approaches for snow mapping: Normalised Difference Snow Index, classification according to the “Parallel piped” and the “Maximum Likelihood” method. The snow maps given in Fig. B2-3 were calculated considering the following three steps:

- 1) Normalised Difference Snow Index (NDSI) > 0 [$NDSI = \frac{VIS - MIR}{VIS + MIR}$],
- 2) channel 5 (TIR) > -10°C, and 3) channel 2 (NIR) / channel 1 (VIS) < 0.

For validation a Landsat 7 ETM image was used. Although calibration of thresholds were necessary in this procedure the derived maps do show high reliance. A detailed validation of

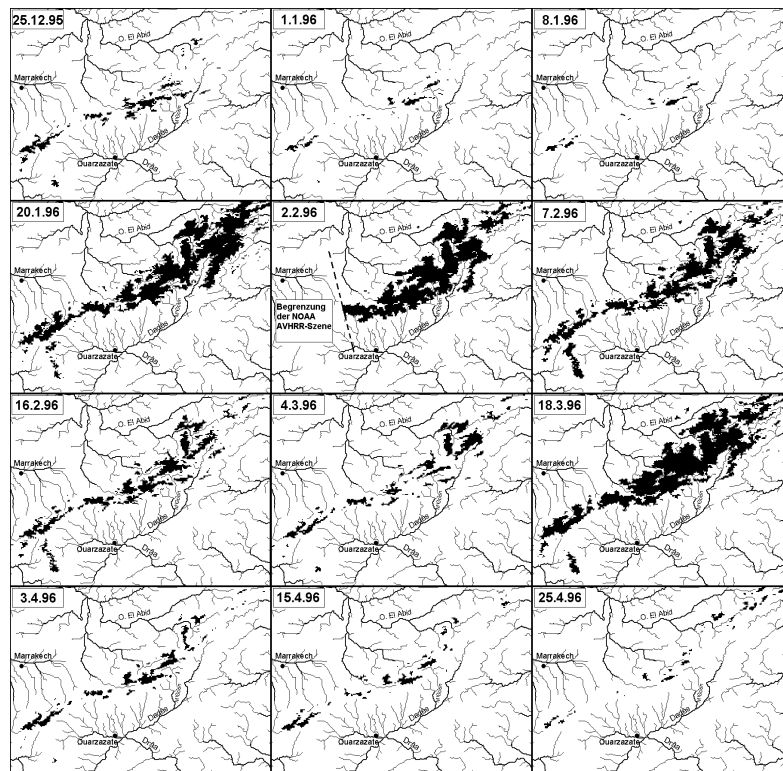


Fig. B2-3: Snow maps of the High atlas derived from NOAA AVHRR satellite images recorded winter 1995/96

stations the wind and rainfall situation August 2001 at El Miyit is shown in Fig. B2-2. The synoptic wind can not be derived from local wind measurements because a small scale wind system near the soil surface is visible. Knowledge concerning these local wind systems are important to understand rainfall patterns controlled by luff-lee effects. In total 12.8 mm of rainfall were observed in August. Comparing these data with a near by rainfall station and satellite images the importance of local

the procedure will be possible by using data from the weather station installed in the High Atlas because they are equipped with automatic snow gauges. Numerous soil temperature data logger were buried in order to determine the spatial and temporal pattern of the snow cover. For simulating the dynamic of the snow cover a modified version of the Snowmelt Runoff Model (SRM, Martinec et al. 1998) will be applied. Because SRM is based on the degree day method, an energy balance approach actual under development in co-operation with subproject B1 will be more promising.

The hydrological situation in the catchment is characterised by small scale variability of soil properties and vegetation coverage. The soils layer is generally thin, often only a few centimetres at the hill slopes. Infiltration, evaporation, and soil water storage is strongly influenced by the high content of stones. While the effect on soil water storage can easily be determined, the consequences for evaporation and infiltration has to be studied in detail. Therefore, an evaporation experiment was started according to the approach of van Wesemael et al. (2000). According to these experiments, evaporation rate is 3 to 5 times lower in soils with a stone coverage compared to pure soils. Furthermore, losses were lowest when the stones are not isolated at the top but enclosed in the soil matrix. The stone content causes large problems in determining the infiltration behaviour. Therefore a rainfall simulator was constructed (see Fig. B2-4). Although the effort in determining infiltration capacity is high, the results are promising. As an example the runoff measured at the test site Bou Skour is given in fig. B2-5. Ponding is reached very fast, the final infiltration rate is already achieved after 15 min. In order to characterise the test sites, hydro-pedological mapping is performed according to the approach of Lange (1999). By measuring soil properties for each hydro-pedotope (soil texture, stone content, infiltration capacity, water holding capacity, etc.) the important information required by the simulation model were determined.

The simulation model applied in this project is a new development based on the work of Lange (1999) and Boer (1999). The grid based model computes soil temperature, evapotranspiration according to the Penman-Montheith approach, soil water dynamics using a simplified two layer concept, infiltration by the Hortan approach and runoff concentration with the Mannings formula. The model is actually tested using data from the southern test site El Miyit. After successful application to the test sites the model will be generalised for application to larger scales.

For the application of the model an accurate digital elevation model (DEM) is required. For three of the test sites DEMs were generated using a differential GPS, for the other this will be performed during the field campaign spring 2002. For larger areas a DEM was derived from digitised topographical maps.

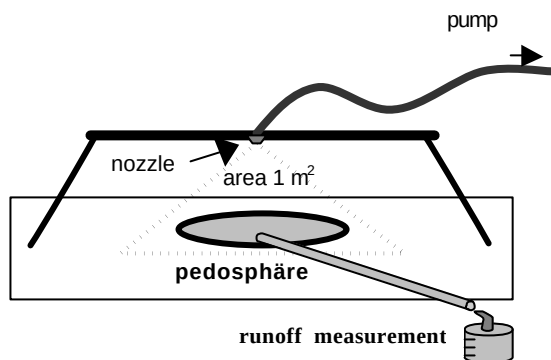


Fig. B2-4: Rainfall simulator used for determining infiltration behaviour (nozzle Veejet, Spraying Systems Co.)

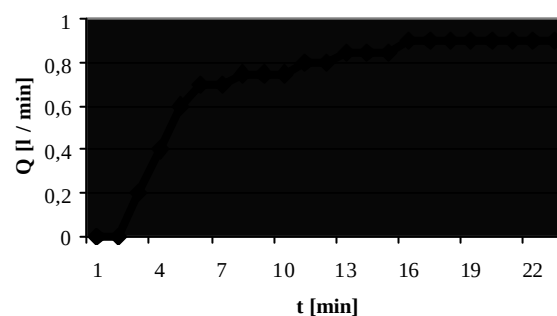


Fig. B2-5: Measured discharge at the test site Bou Skour (stone coverage > 80%) Rainfall intensity was 1.5 l/min, ponding occurs after two minutes

Because no soil maps were available for the investigated catchment, a detailed soil mapping (about 100 soil profiles) was performed. In co-operation with the hydro-pedological mapping, soil probes were taken along different soil catenas. Soil type as well as soil texture, salinity, organic matter content etc. were determined and stored together with relief properties (slope, slope length etc.) in a database. This database is required for deriving soil-relief-land use relationships which will be used for the regionalisation of the soil properties. From the field observations the fundamental relevance of the vegetation for the small scale variability of soils is visible. Vegetation acts as a sediment trap and is therefore important for soil conservation. At the test site Tichki about 4 l of soil per m² were trapped in the vegetation at the upper slope and about 8 l soil per m² at the middle slope. Because the texture of the

trapped soil as well as the soil depth differ between vegetation covered and vegetation free zones the small scale spatial variability of soil water and runoff behaviour is closely linked to the vegetation dynamics. Therefore, detailed experiments were carried out in close co-operation with the subproject B3. In addition to the soil mapping soil erosion measures were installed at selected sites. The combination of the results from sediment traps, erosion pins with map of the erosion damage will be the base for the erosion assessment.

The investigation of the hydrogeology focuses on the upper Drâa catchment in the first phase. Because only a rough geological map is available, a detailed geological mapping of the test sites situated in the High Atlas and in the basin of Ouarzazate was performed. This mapping at the local scale results in detailed knowledge concerning the hydrogeological classification of the test sites and their related springs and wells. As an example, fig. B2-6 shows the hydrochemical classification of the groundwater in the test site Ameskar, High Atlas, which is determined by the geological situation. Some springs are characterised by a distinct mixing of the general clearly geogene determined water types (e.g. basalt, carbonates). Mixing portions show a distinct dependence on the hydraulic situation. However, the hydrochemical pattern could not be used to solely determine the catchment area of the springs. Therefore environmental isotope measurements have been performed in the northern Drâa catchment area, showing a reasonable correlation of $\delta^2\text{H}/\delta^{18}\text{O}$ -data with the meteoric water line (Fig. B2-7: MWL: $\delta^2\text{H} = 8 \delta^{18}\text{O} + 10 \text{‰}$). Deviations are partly due to enrichments by evaporation effects. Based on the rare rainwater data available no local input function for the $\delta^{18}\text{O}$ - and $\delta^2\text{H}$ -content of the rainwater could be established so far. However, the regular sampling of rainwater started in autumn 2001. Therefore a determination of the various catchment areas of the springs will be performed soon.

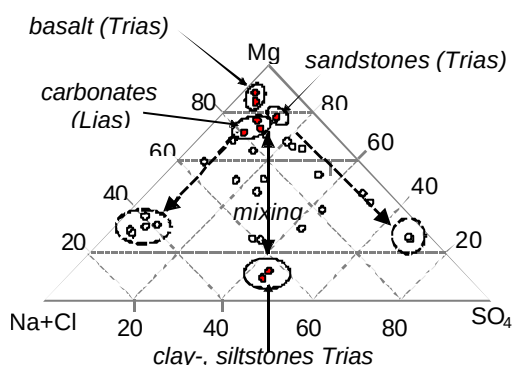


Fig. B2-6: Triangle diagram of selected springs of the test site Ameskar

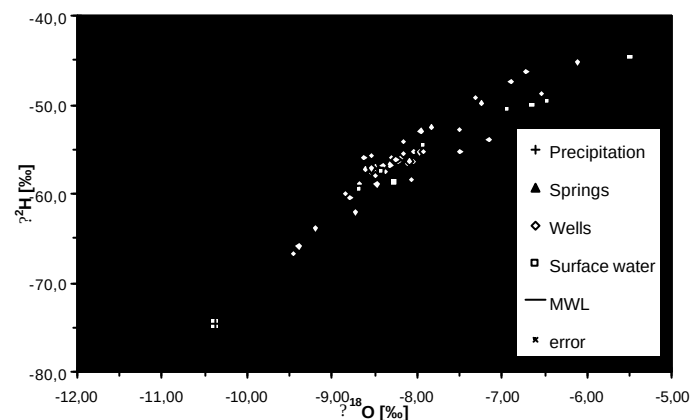


Fig. B2-7: Analysis of the isotopes of all investigation sites of the upper Drâa catchment. MWL = meteoric water line

References

- Boer, M.M. (1999) Assessment of dryland degradation – linking theory and practice through site water balance modelling. *Nederlandse Geografische Studies* 251. 291 S.
- Lange, J. (1999): A non-calibrated rainfall-runoff model for large arid catchments, Nahal Zin, Israel. *Freiburger Schriften zur Hydrologie* 9, 139 S.
- Martinec, J., Rango, A., Roberts, R. (1998): *Snowmelt Runoff Model (SRM) User's manual*. Updated Version. Geogr. Bernensia, Series P, Vol. 35, Bern.
- van Wesemael, B., Mulligan, M. and Poesen, J. (2000). Spatial patterns of soil water balance on intensively cultivated hillslopes in a semiarid environment: the impact of rock fragments and soil thickness. *Hydrological Processes* 14.

Subproject B3

FUNCTIONAL RELATIONS BETWEEN VEGETATION DYNAMICS, WATER CYCLE AND HUMAN INFLUENCE

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Key words: Remote sensing, land cover classification, vegetation dynamics, permanent monitoring plots, spatial related evapotranspiration, resource management

Abstract:

Subproject B3 deals with vegetation-based regulating mechanisms which control the regional water balance. The selected approach is based on the coupled spatio-temporal pattern analysis, and integrative process oriented methods to assess the regional evapotranspiration. Finally, research is oriented towards investigations on the technical aspects of water efficient crop management and sustainable pastoral land use systems.

Results:

Organisational progress

During the first project phase, the logistic infrastructure of the subproject B3 was completed. Ten fencing experiments and 34 permanent monitoring plots (PP) have been established along the IMPETUS-Transect. Each permanent plot covers an area of 100 m². The census units are ¼ m², the data refer to the rooting point of an individual plant.

The floristic exploration of the study area has proceeded successfully. 150 vegetation relevés were established in the upper and middle Drâa-Catchment. Each plot is geo-referenced and linked to the GIS of the study area.

In co-operation with ORMVAO, a weighing lysimeter and a climate station were installed at the oasis of Zagora (Asrir) in order to measure evapotranspiration (ET) in arable lands.

Analysis of spatial patterns in landscape and vegetation

Macro-scale: The spatial distribution of different land use and land cover categories of the Drâa catchment were derived from LANDSAT-ETM data, by means of a hybrid supervised classification. This necessitated the collection of land cover and land use parameters from representative observation points (e.g. vegetation coverage, ~height, ~composition, spectral reflectance and estimation of leaf area index). Linear Spectral Unmixing, Maximum Likelihood and Knowledge Based Classification were applied to the LANDSAT-ETM-data. The overall accuracy of the first classification result is 90 %.

The first classification of the relevés gives an explicit trisection of the vegetation, and it's affiliation to three floristic regions in the study area: Mediterranean vegetation on the slopes of the High Atlas, and the northern slopes of the Antiatlas, Irano-Turanian steppes in the basins, and finally Saharan vegetation units from the Antiatlas down to the Algerian border.

Micro-scale: At the spatial scale of the test sites, a structural and functional analysis of vegetation patterns has been started. At several test sites, vegetation was mapped at an individual level, using a transect approach with a differential GPS. An elevation model, with high resolution has been compiled. Hence, the spatial distribution and patterns of different taxa, with regard to their ecological affinities, could be analysed. This approach enables the transfer of insights that are acquired from the permanent plots to the landscape level.

Analysis of vegetation dynamics

NOAA-AVHRR-data: In order to analyse the seasonal dynamics within the vegetation in the study area, daily NOAA-AVHRR data were downloaded from the NOAA Satellite Active Archive (starting 01/1999). Using the software TERASCAN, an automatic processing chain was developed for the necessary pre-processing of the data, including geo-correction and calibration. Also, the Normalised Difference Vegetation Index was calculated on a daily basis. NDVI images are used in order to observe the response of the vegetation to rainfall.

LANDSAT-CORONA-IKONOS: In order to carry out a comparative calculation of the reflectances of LANDSAT-MSS (1974), LANDSAT-TM (1987) and LANDSAT-ETM (2000) images, a radiometric and topographic normalisation had to be applied to the data. Ground control points in x, y and z co-ordinates for the geocoding of CORONA and IKONOS images were recorded by means of a differential GPS. High resolution digital elevation models for two test regions were generated out of CORONA stereo data.

The preliminary results of the land use change studies show interesting increases in vegetation in the irrigated areas north, and north-west of Zagora, while in other sections of the Drâa, a significant decrease in vegetated surfaces could be detected.

Monitoring plots: Parameters recorded for each individual plant inside the PP comprise: increase in biomass, frequencies of flowering and fruiting, as well as germination and mortality. The inventories of the PP can be mapped at the scale of individuals (Finckh & Staudinger, in press). They offer the opportunity to detect hardly noticeable long-term changes, either due to varying physical conditions, or due to different grazing intensities in the ten selected ecosystems of southern Morocco. As vegetation structure influences infiltration, run-off and ET, evaluated data from permanent plots are indispensable in order to properly model the regional water balance.

Vegetation parameters, controlling the regional water balance

Measurement of ET: ET measurements are carried out with different combined measurement systems. A leaf wetness sensor (RESI) was applied for the recording of the diurnal transpiration dynamic of a species. The absolute transpiration rates were attained by calibrating these data with a porometer (LICOR). This approach will be repeated in different seasons so that the seasonal transpiration rhythms of each plant species can be documented. Further information on the potential transpiration, water stress situations and the water stress modulation system of these species will be derived by measuring the actual water potential with a Scholander pressure chamber. The ET of dominant plant species and of different crops that are grown in the Oasis of Zagora are measured at the test sites of El Miyit and Taoujgalt. Oasis ET will also be measured with a weighing lysimeter. It is planned to evaluate the water consumption of selected trees and shrubs with a flow meter.

Determination of biomass: Finally, the biomass of dominant plant species was determined in order to extrapolate the transpiration rates (gathered from single leaves) from the individual to the landscape level. Therefore, the dimensions of randomly selected individuals were determined. Subsequently, these plants were harvested. The transpiring and non-transpiring biomass was separated. For each of the dominating species, a calibrated transpiration-biomass curve will be calculated. In combination with the vegetation maps of the permanent plots and the test sites, the area related transpiration rate of the stands can be determined efficiently.

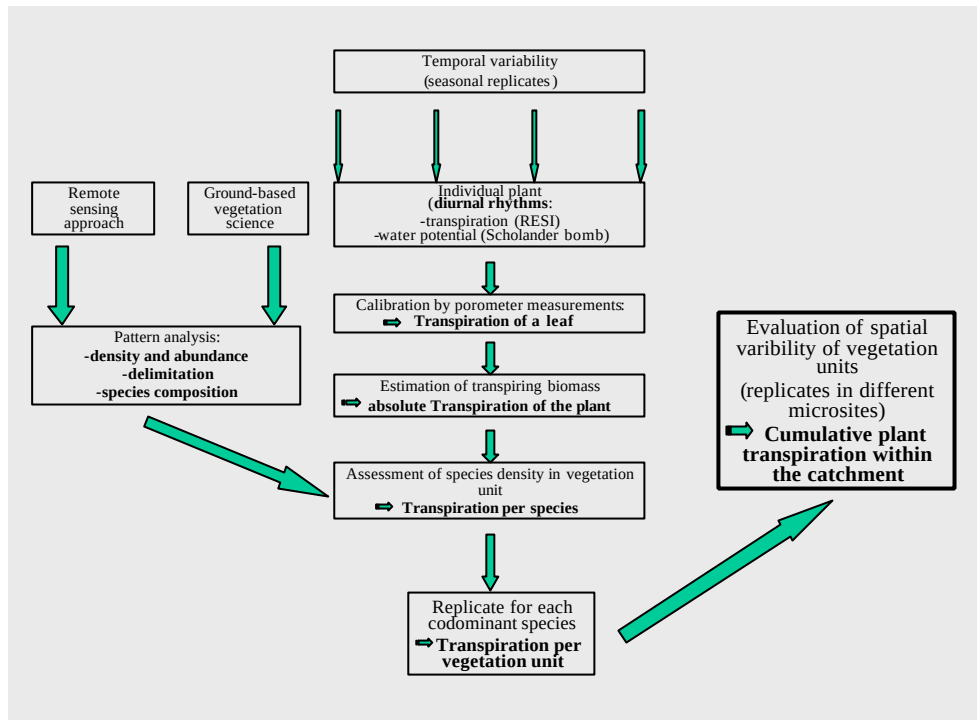


Fig. B3-1: Spatial related evapotranspiration

Development of resources management tools

With regard to IMPETUS's aim to develop efficient and sustainable resource management plans, the subproject B3 aims at developing concepts for water-saving pastoral and agricultural techniques. Hence, the initial focus has been put on restoration techniques.

Plant establishment with hydrogels: Hydrogels provide a possibility to increase the soil water storage capacity and to minimise evaporation. We will try to use hydrogels for plant establishment on eroded soils. This procedure might support the restoration of degraded rangelands.

At first, greenhouse experiments with two different polyacrylates (HYSORB, STOCKOSORB) and one silicate (BETASOIL) were carried out. Subsequently, field experiments were started at two different locations in Morocco. A local variety of winter wheat is cultivated at the field station of Asrir and experiments with *Atriplex halimus* are running. Finally, *Citrus limon* saplings are used for a pot experiment with nine replicates. Preliminary results indicate that the treatments with polyacrylate-based hydrogels perform better under water stress than those with the silicate gel.

Rangeland management: Rangeland degradation due to overgrazing and firewood collection is the main ecological problem in these areas. Therefore, as a first approach to quantify impacts of pastoralism on the vegetation, ten enclosure experiments have been installed. The comparison of coupled PP inside and outside the fenced areas allows the evaluation of grazing impacts on biomass production and species composition. Depending on the results derived during the first phase, we will initiate controlled grazing experiments in the next phase, in order to define the carrying capacity of the different ecological units.

Perspectives

We are intending to establish stand ET balances at selected test sites during the remaining time of the first phase.

The monitoring of the permanent plots has to be continued in order to assess the impacts of climatic variability and changing land use patterns. A preliminary vegetation map of the Drâa

catchment will be completed by the end of the first project phase. In the second phase, vegetation classification and cartography will be refined to a higher resolution, thus, serving as a basis for spatially orientated vegetation modelling.

Temporal aspects of long and short-term vegetation changes will be analysed over time and space, using multi-temporal sequences of different remote sensing media. This method will support the measures to identify the driving forces of degradation and desertification.

Links to other subprojects and research groups

Field experiments are carried out in close co-operation with the local population. Links have been established with the *Institut Agronomique et Vétérinaire Hassan II* and other Moroccan research institutions. We are also co-operating with the projects *ROSELT* and *PBTHA (Projet de Biodiversité et Transhumance dans le Haut Atlas)*. The RSRG is co-operating with Prof. Goossens from the University of Gent (Belgium) and with Dr. M. Canty (FZ Jülich). Close contacts exist with the BIOTA-project, especially, with regard to methodology and technical co-operation.

Our strong transdisciplinary research link with the socio-economic subproject B4 is based on determining the long-term demographic trend, survival strategies and economic development of mobile pastoral groups with regard to land use and grazing pressure. These key factors ultimately affect the vegetation dynamics. Currently, in a joint initiative with the GTZ (Zagora), the human impacts on the Tamarisk forest west of M'Hamid are being investigated as well. Interdisciplinary activities are also being carried out with the subproject B2, with regard to aspects of infiltration, run-off and microclimatic conditions.

References:

- Altmaier, A., Kany, C., Schmidt, M. & Menz, G. (2001): Generierung eines 3D-Modells aus CORONA-Satellitenbildern. J. Strobl, T. Blaschke und G. Griesebner (Hrsg.): Beiträge zum AGIT-Symposium Salzburg 2001, Angewandte Geographische Informationsverarbeitung XIII.
- Finckh, M. & Staudinger, M. (in press): Macro- und mikroskalige Ansätze zu einer Vegetationsgliederung des Draa-Einzugsgebiets (Südmarokko). *Berichte der Reinhold-Tüxen-Gesellschaft*.
- Goossens, R., Schmidt, M., Altmaier, A., Benoit, F., Menz, G. (2001): Extraction of Digital Elevation Models and ortho-images from CORONA KH4B data. *Proceedings of ISPRS workshop: High resolution mapping from space 2001*, Hannover, Germany.
- Menz, G., Schmidt, M., Finckh, M., Jürgens, N. (2001): Assessment of spatio-temporal vegetation dynamics in the Drâa catchment using a multisensor approach. *Proceedings of the international symposium: Arid Regions Monitored by Satellites: from Observing to Modelling for Sustainable Management*, Marrakesh, Morocco.
- Rao, K.S., Phalke, S.M., Sakalley, J., Schmidt, M.: Assessment of Geo-coding and Height Accuracy of the DEM derived from SRTM. Submitted to *IEEE*
- Schmidt, M., Goossens, R., Menz, G. (2001a): Processing techniques for CORONA satellite images in order to generate high-resolution digital elevation models (DEM). *Proceedings of the 21 EARSeL Symposium* May 2001. Paris, France.
- Schmidt, M., Goossens, R., Menz, G., Altmaier, A., Devriendt, D. (2001b): The use of CORONA satellite images for generating a high-resolution digital elevation model (DEM). *Proceedings of the IGARSS 2001 Conference*, July 2001. Sydney, Australia.
- Staudinger, M. & Finckh, M. (2002): Räumliche Vegetationsmuster in ariden Gebieten Südmarokkos – Klassifizierung zugrunde liegender Mechanismen. – in: Akhtar-Schuster, M. & Veste, M. (eds.) *Proceedings Desert Ecology*, Hamburg, in prep.

Subproject B4

WATER DISTRIBUTION AND WATER CONFLICTS

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Keywords: water management, water rights, water conflicts, water distribution, socio-economic development, institutions, water use, irrigation

Abstract:

The aim of the B4 sub-project is to analyse the water distribution and water use in the Drâa valley in Morocco. Local land and water rights have to be identified, described and related to the power-position of various social groups involved. Social stratification along ethnic, tribal-agnatic or economic lines is common in most of the communities. Water distribution often is organised according to this stratification of society, which can be demonstrated in various settings along the Drâa valley. Although local water distribution systems are still functional in many rural settlements, modern influences like labour migration or tourism haven altered the traditional water relations in the urban context, but also in some rural areas. To cover the full range of cultural variations of the water use systems, the research area of the anthropological work-package was extended. After the first half of the ongoing research period areas in the middle and upper Drâa valley were included.

Results:

Dynamics of socio-economic change in water management among agricultural and pastoral communities in the southern and middle Draa valley

The sedentarisation process and the interplay between nomads and sedentary groups; the dynamics of tribal institutions; the strategies of domestic groups in water distribution

Ethnological fieldwork mainly focuses on the socio-political dynamics of pastoral and sedentary groups in the southern Drâa valley. The access to, the distribution of, and the conflict over natural resources - especially water and land - are analysed. Three groups are the object of the inquiry in the Ktawoua region: 1) The “persisting nomads” who mainly belong to the Aït Unzâr tribe, a sub-fraction of the Aït Atta Berber confederation; 2) The former nomads who settled in marginal quarters of the urban centre of Tagounite since the mid-70s; 3) The mixed population of Arab-speaking Draoua farmers and Berber-speaking Aït Unzâr pastoralists, who settle in the *ksar* Tiraf, in the extreme south-west of Ktaoua Oasis.

In Tiraf, the access to water still seems to be managed along traditional social and status categories. The basic division remains the one between Draoua and Berbers. This becomes obvious in: 1) the organisation of the distribution of drinking water at the collective taps in the *ksar*; 2) the lineage-based partition of water rights for irrigation; 3) the limitation of water rights concerning wells outside the cultivated space of the oasis; 4) the solidarity networks based on ethnic, tribal-agnatic or status identities. This persistence of a well-rooted social background does not neglect social mobility, often linked to migration and the spreading of capitalist labour relations.

The importance of local institutions in managing the socio-economic life is underlined by two features: The “harmonious”, non-contradictory coexistence of national “modern” state elected functionaries and traditional tribal non-elected representatives in local administration on one hand, and the relevance of an interplay between Aït Unzâr nomads and the sedentary tribal groups of the Draoua in managing all daily matters on the other. This is well illustrated in the vitality of the two tribal assemblies in Tiraf, representing and organising their respective groups. In a context of spatial and socio-economic marginality, the existence of such autonomy and capacity of “bottom-up” management is particularly important as a counterbalance to state institutions as the AUEA.

A more quantitative analysis based on demographic and socio-economic data showed a number of issues and a remarkable flexibility in the distribution of the household tasks to cope with drought and crisis. Nomads and former nomads differ from the established sedentary population in choosing different economic strategies, nomads being most oriented towards military service, while the latter are more attracted by labour migration and investments in education. Marriage patterns also offer an interesting insight into strategies of adaptation to rapid changes and resource scarcity.

Strategies of water acquirement in a village of the middle Drâa valley

Fieldwork was done in Blida, a village on the left edge of the Southern wadi Drâa. The work focused on the socio-political life and the local institutions in the village as well as on the availability and distribution of water resources. The village has about 113 households. Its population consists of the following five social groups 1) *Ait Isfoul*, 2) *Draoua*, 3) *Reggaga*, 4) *Abid* and 5) *Chorfa*. Life in the village is characterized by strong social, political and economical hierarchies. In Blida, the water situation of an individual, a residential or descendant group is closely related to the power-position occupied in this socio-economic structure.

Water in Blida is available in various forms: water pumps (wells), water reservoirs *matfia*, and river water. Water is distributed according to the local water rights *nouba*. Having access to these water-sources depends either on the rigid “local” water law, on the economic power, or on the social networks between and within the social groups. Irrigation water comes mainly from the *Mansour Edhahbi* dam. It is distributed through the “local” canalisation, the *segua*. Branches of the *segua* that lead to the plots of irrigated fields are named after lineages living in the village. Farmers who need water for agricultural production but who are not entitled to *nouba* rights have only few options. They can either dig a well and install a water pump, or buy water on an hourly basis from other farmers owning a water-pump. The scarcity of the irrigation water necessitates the co-operation of social groups, or urges individuals to seek a patron/client relationship. Because of the salinity of most wells, drinking water for almost all the social groups is provided by the dam. In some cases, the water of wells having the best water quality is also used as drinking water.

To participate in decision-making processes all social and descendant groups are represented in the *qabila*. The position of *sheikh*, which is nowadays a governmental position, has always been held by members of the same descendants group. Decisions related to water are mostly made by these local institutions, although the AUEA was officially created by the government to manage and control water distribution.

Recently the research area has been extended to include another oasis north of the areas already studied. In the palm grove of Tinzuline, anthropological research focuses on the household economy of the mixed population. In addition, the influence of state or para-state organisations on local water distribution systems is being studied.

Urban and rural water users

Changes of water management in the upper Drâa valley

Different institutions and administrative bodies are involved with the water management in Ouarzazate. Conflicts between water users and these institutions can be observed on several levels:

On the large scale, growing competition between urban and rural water use is visible. Due to the population growth and the urban development, the demand for drinking water is rapidly increasing in Ouarzazate. The water of the dam Mansour Ed Dahbi, which should supply water for irrigation in the lower Drâa-Valley, is used to satisfy the urban needs. Although the water consumption for urban purposes is rather low, compared to the annual evaporation, after long dry periods, the water of the dam Mansour Ed Dahbi gets scarce. The actual situation in the fourth dry year in sequence, is marked by the absence of irrigation water for annual cultures like maize, henna and lucerne. The irrigation campaigns could only support the permanent cultures like date- and almond trees and recharge the groundwater.

On the small scale a difference in the access to, and the quality of the drinking water supply in Ouarzazate is evident. In the traditional rural quarters of the town not all households have access to the public water supply. In two rural quarters at the eastern outskirts access is restricted to two hours a day. The drinking water quality declines during the dry season in the areas north of the riverbed. The quality is constantly good in the areas south of the oued. The people react on the poor water quality during the dry season by looking for better drinking water facilities on the other riverside or at springs or wells.

The poor water quality in the dry season results from the absence of a sewage plant for the waste-water of the city. The waste-water is used without treatment for irrigation by the farmers downstream, who have their fields near the outlet on the northern river terrace. The local water supply authority ONEP is an institution with an autonomous budget. After the construction of the treatment plant and the high running costs for the filtration, the authority was forced to expand their distribution net and to sell as much water as possible. The economic use of water is not their major interest, but the balance of the budget. For private households and the administration, the water price is increased with a growing consumption. The major consumer - the industrial sector - has a fixed price.

In the region of Ouarzazate not only the water use and the water distribution has changed, as a result of the socio-economic development, but also the symbolic value of water as a scarce and precious element. Water is now considered as a modern, commercial good, which can be bought, sold and wasted.

Changes of water management in the upper Drâa valley

Conflicts and modes of regulation in the Higher Atlas Mountains

In this work package water distribution systems were analysed and related to arising conflicts and their modes of regulation in the context of social and political upheavals. The research area is located at the foot of the Tassila Zatt mountains and is inhabited by several fractions of the Tdili, a Berber group. The intensified cash crop production together with significant investments of migrant workers led to an increase of social differentiation in rural communities and an alteration of the traditional water distribution systems. Besides the, at least temporary, shortage of water, the introduction of motor pumps enabled an intensification of irrigated farming independent of the traditional water distribution system.

Most conflicts in the rural communities arose from the problems associated with the supply of drinking water. The construction of reservoirs and pipelines exhausted the financial means of many communities and damaged the village solidarity. Fractions of the rural population with access to financial support from migrant workers, build houses with modern sanitary installations consuming much more water, than an average household. Although prices for

drinking water are graduated - higher consumption means higher cost per m³ - the feeling of inequality or injustice persisted. In addition, all the expensive reservoirs could not guarantee a continuous water supply. The increase in population, beside the high water consumption of some elaborated household, created a rapidly rising demand in drinking water.

The decline in available water also affects the agricultural sector. As a consequence cultivation of summer crops such as maize and potatoes did not take place in the last years. Again, the failure of summer crops did not affect all households in the same way. While households with access to money from migratory workers could compensate the loss, members of poorer families were forced to work as day labourers of the fields of large landowners. In years with low rainfall, when the demand for farm labour was low, the pressure to migrate outwards was high.

In order to examine the significance of these findings, a second research area west of Toundout in the Imidirt valley was chosen. Current research focuses on the impact of the regional administration of Ghasset and Toundout on the local political actors. Moreover, anthropological research about local knowledge systems is carried out in the vicinity of some botanical research areas. These studies aim at comparing scientific and local concepts of knowledge about natural resources.