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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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University of Cologne Institute of Geophysics and Meteorology **HD Dr. habil. A. Fink (Director)** Kerpener Str. 13 D-50923 Köln	University of Bonn Steinman Institute - Geology **Prof. Dr. B. Reichert (Vice Director)** Nussallee 8 D-53115 Bonn
Telefon: 0221-470 3819 Fax: 0221-470 5161 E-mail: fink@meteo.uni-koeln.de	Telefon: 0228-73 2490 Fax: 0228-73 9037 E-mail: b.reichert@uni-bonn.de

Kontaktadresse:
Universität zu Köln
Institut für Geophysik und Meteorologie
Dr. Michael Christoph (Geschäftsführer)
Kerpener Strasse 13
D – 50923 Köln
Germany
Telefon: +49 221 470 3690
Fax: +49 221 470 5161
E-mail: christoph@meteo.uni-koeln.de

Contact us:
University of Cologne
Institute of Geophysics and Meteorology
Dr. Michael Christoph (Project Manager)
Kerpener Strasse 13
D – 50923 Cologne
Germany
Telephone: +49 221 470 3690
Fax: +49 221 470 5161
E-mail: christoph@meteo.uni-koeln.de

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Zusammenfassung

Das Gesamtziel der 3. Phase des IMPETUS Westafrikaprojektes war die Entwicklung von Entscheidungsunterstützungssystemen, sog. „*Decision Support Systems*“ für lokale Entscheidungsträger im Hinblick auf ein nachhaltiges Management der knappen Ressource „*Wasser*” in zwei Flusseinzugsgebieten nördlich und südlich der Sahara, nämlich das Wadi Drâa in Südostmarokko und der Ouémé in Benin. Diese interdisziplinäre und anwendungsorientierte Aufgabenstellung wurde durch die einzigartige Konzentration einer Vielzahl von Wissenschaftlern sowohl der Geistes- als auch der Naturwissenschaften erfolgreich innerhalb des Projektzeitraumes bewältigt. Die im Gesamtverlauf des Vorhabens gewonnenen Ergebnisse finden Eingang in die verschiedenen Entscheidungsunterstützungssysteme, deren erfolgreiche Implementierungen an den entsprechenden Partnerinstitutionen als Ausgangsbasis für die in der nachfolgenden Phase, der sog. Verstetigungsphase, zu erprobende Operationalität und Weiterentwicklung der Systeme durch die Partner dienen.

Nachfolgend werden die wichtigsten übergreifenden Ergebnisse der dritten dreijährigen Förderphase aufgezählt:

Die Entwicklung einer Reihe von räumlichen Entscheidungsunterstützungssystemen (SDSS) in begrenzter Zeit ist eine Herausforderung für Software-Entwickler. Um möglichst effizient und flexibel zu sein, wurde ein sog. *SDSS-Framework* entwickelt und implementiert. Das SMILE-Framework versucht alle, teilweise auch im Widerspruch stehenden Anforderungen zu erfüllen, wie z.B. leichte Bedienbarkeit und die gleichzeitige Verfügbarkeit von komplexen Funktionen. Diese Java-basierte Software erlaubt eine gute Anpassungsfähigkeit, einfache Wartung, breite Möglichkeit der Integration verschiedener Modelle und Werkzeuge und eine hohe Effizienz in der Entwicklung von SDSS. Es war das auserkorene Ziel, Entwicklern und wissenschaftlichen Nutzern die Möglichkeit zu geben, sich auf die wissenschaftlichen Inhalte zu konzentrieren und nicht perfekte Programmierkenntnisse zu erlangen.

Innerhalb von IMPETUS wurden etwa 30 verschiedene Systeme mit Hilfe des SMILE Frameworks entwickelt. Die Bandbreite der Themen, die in dieses integrierte decision support Framework (IDSS) eingebunden wurde, reicht von einem Wettergenerator über integrierte hydrologische Modelle bis hin zu sozioökonomischen Systemen. Zielgruppen für diese Systeme sind Regierungs- und Nichtregierungsorganisationen sowie wissenschaftliche Institutionen in Benin und Marokko.

Ergebnisse für Benin:

Die Ernährungssicherung in Benin ist unter anderem gefährdet durch eine Degradation der Bodenfruchtbarkeit bedingt und beeinflusst durch verschiedene Bestimmungsfaktoren wie Bevölkerungsdruck, Bildung und Einsatz von Dünger. Um die Auswirkungen der Bodendegradation, die besonders in den dicht besiedelten Räumen auftritt, zu mildern, sind in den letzten Jahren Anpassungsstrategien wie verbesserte Brachesysteme, Nutzung der Inland Valleys sowie der Einsatz von Mineraldünger beobachtet worden. Im Teilbereich „Ernährungssicherung in Benin“ wurde in einer gemeinsamen Anstrengung mit nationalen Institutionen eine Bestandsaufnahme der In-

land Valleys in Benin durchgeführt. Gleichzeitig wurde ein Informationssystem entwickelt, das den Zugang zu den erhobenen Daten erleichtert und eine Bewertung des Nutzungspotentials ermöglicht (BenIVIS: Benin Inland Valley Information System). Die Effekte von Brachesystemen und Bracheverfügbarkeit sowie der Anwendung von mineralischen Düngern im Zusammenspiel mit Klimaveränderungen auf die Bodendegradation und die landwirtschaftlichen Erträge können mit dem räumlichen Entscheidungsunterstützungssystem PERDRO (Protection du sol et durabilité des ressources agricoles dans le bassin versant de l'Ouémé) erfasst werden. Simulationsläufe auf der Grundlage von Klimaszenarien bis zum Jahr 2050 deuten an, dass in den nächsten fünf Jahrzehnten mit einer abnehmenden Wasserverfügbarkeit im Oberlauf des Ouémé gerechnet werden kann, die, zusätzlich zum Problem der Bodendegradation, zu weiteren Ertragsrückgängen führen würden. Die ökonomische Bewertung eines neuartigen Düngemitteleinsatzes mit dem Modell BenIMPACT zeigt, dass die Wirtschaftlichkeit der Anwendung von Mineraldünger nach wie vor gering ist und damit das Düngeniveau zu niedrig bleibt, um die Bodenfruchtbarkeit, die Bodennutzung und die Nahrungsmittelerzeugung zu stabilisieren. Arbeitskraft ist immer noch zu billig, um arbeitssparende Innovationen einzuführen. So lange es billiger ist, Wälder zu roden als Mineraldünger zu nutzen, um denselben Ertrag zu ernten, wird man keine wesentlichen Änderungen in den beobachteten Trends erwarten können. Dauerhaftes ökonomisches Wachstum in Verbindung mit höheren Einkommen und Löhnen würde, bei sonst gleichen Rahmenbedingungen, zu einer Trendwende in der exzessiven Umwandlung von natürlichem Savannenwald zu Ackerland und in der Bedrohung der Ernährungssicherheit beitragen.

Um in Zukunft Wasserverfügbarkeit und Wasserbedarf in Einklang zu bringen sowie zukünftige Bodendegradierung abzuschätzen, bedarf es eines umfassenden Verständnisses der natürlichen Prozesse und der gesellschaftlichen Gegebenheiten sowie plausibler Szenarien zukünftiger wirtschaftlicher, demographischer und klimatischer Entwicklungen. Um die zukünftige Wasserverfügbarkeit abzuschätzen, wurde ein regionales Klimamodell mit einem hydrologischen Modell verknüpft, das auch Landnutzungsänderungen berücksichtigt wie sie von einem Zellulären-Automaten-Modell projiziert werden. Zukünftige Wasserbedarfe wurden berechnet, indem der Trend im Bevölkerungswachstum mit dem Pro-Kopf-Wasserverbrauch kombiniert wurde. Letztere Zahl wurde anhand einer regionalen Umfrage bei privaten Wassernutzern abgeschätzt. Darüber hinaus wurde auch der Wasserverbrauch für Viehhaltung, landwirtschaftliche Bewässerung und Industrie in Betracht gezogen. Die Wasserverfügbarkeit unterliegt einer hohen zeitlichen Veränderlichkeit aufgrund der natürlichen Abfolge von Trocken- und Regenzeiten von Jahr zu Jahr. Und selbst wenn physische Wasserknappheit nicht der wichtigste limitierende Faktor zu sein scheint, ist doch der Zugang zu Wasser in einigen Teilen des Flusseinzugsgebietes beschränkt durch die geringen ökonomischen Kapazitäten der Versorger und Verbraucher. Bodendegradierung durch Wassererosion wurde mit Hilfe des Modellsystems SWAT berechnet und die zuvor erwähnten Szenarien verwendet. Sowohl Klima- als auch Landnutzungsänderungen werden die Bodenerosion in gegensätzlicher Weise beeinflussen, aber die Landnutzungsänderung wird die zukünftige Entwicklung dominieren. Eine genauere Analyse zeigt, dass ein großes Missverhältnis zwischen „hot spots“ der Bodendegradierung und der Wasserknappheit von Region zu Region besteht. Die Ergebnisse und die hier diskutierten Modelle wurden in Entscheidungsunterstützungssysteme implementiert, die Entscheidungsträgern helfen sollen, die Auswirkungen verschiedener Handlungsoptionen zu bewerten.

Landnutzung und Landbedeckung sind kritische Komponenten des Ökosystems und Änderungen in der Landnutzung und Landbedeckung haben definierte und vorhersagbare Auswirkungen auf Klima, Hydrologie, Biodiversität und biogeochemische Stoffkreisläufe. In Benin verändern sich die Landnutzung und die Landbedeckung mit hoher Geschwindigkeit, hauptsächlich infolge der Verdopplung der Bevölkerung im Laufe der nächsten 30 Jahre. Um die gegenwärtigen und zukünftigen Landnutzungs- und Landbedeckungsänderungen abzuschätzen, wurde das fernerkundungsbasierte regionale Landnutzungsmodell und Informationssystem LUMIS entwickelt. LUMIS ist ein räumlich explizites, rasterbasiertes Modell der Landnutzungs- und Landbedeckungsänderung. Basierend auf einem logistischen Regressionsansatz werden Landnutzungsänderungen von einer Reihe natürlicher, demographischer, wirtschaftlicher und kultureller Faktoren gesteuert. Die Parametrierung von LUMIS erfolgte für die Periode von 1991 – 2002, für die detaillierte ökologische und sozioökonomische Daten zur Verfügung stehen. Die Modellgenauigkeit kann als mittel bis hoch eingestuft werden mit einem Integralwert zwischen 0,7 und 0,9. Die Ergebnisse zeigen, dass die Bevölkerungsdichte und der Abstand zu Straßen die beherrschenden Faktoren für die Umwandlung von natürlicher Savanne in Ackerland sind. Unter Verwendung der IMPETUS Landnutzungsszenarios B1 (wirtschaftliches Wachstum), B2 (wirtschaftliche Stagnation) und B5 (Intervention) wurden zukünftige Landnutzungsänderungen bis zum Zieljahr 2025 berechnet und die möglichen Konsequenzen auf die Wasserverfügbarkeit und die Nahrungssicherung analysiert. Während das B1-Szenario einen verringerten Verlust von Wald für landwirtschaftliche Nutzung zeigt, ist das B2-Szenario charakterisiert durch eine hohe Entwaldungsrate. Darüber hinaus zeigen beide Szenarien ein erhöhtes Wachstum von Siedlungen, die entweder durch eine positive wirtschaftliche Entwicklung verursacht ist mit einer zunehmenden Zahl von nicht-landwirtschaftlichen Jobs in den Städten oder durch eine hohe Landflucht verbunden mit einer hohen Zahl von Arbeitsuchenden, die in die Nähe der Städte ziehen. Modellierung der Landnutzungs- und Landbedeckungsänderung mit Hilfe von LUMIS kann von besonderem Nutzen für die Identifizierung und Überwachung der kritischen Entwicklung von „hot spots“ sein. LUMIS ermöglicht nicht nur die frühzeitige Entdeckung von Landnutzungs- und Landbedeckungsänderungen, sondern auch die Planung effektiver Gegenmaßnahmen.

Das Management natürlicher Ressourcen in Zentralbenin erfährt zurzeit beträchtliche Veränderungen. Modifizierungen in der Bodenbesitzstruktur und im Wasserversorgungsmanagement gehen einher mit Prozessen der Dezentralisierung, der Demokratisierung und der Einführung neuer Politiken. Gebräuchliche Besitzstrukturen sind hoch dynamisch und variieren von Ort zu Ort. Der Konflikt zwischen diesen etablierten Traditionen und nationaler Landgesetzgebung erfordert die Koexistenz moderner und traditioneller Landrechte, gesetzlichen Pluralismusses und gesetzlicher Ungewissheit. Streitigkeiten um Land treten auf, der Kauf von Land ist problematisch und Eigentumsrechte sind ungleichmäßig verteilt. Darüber hinaus ist Land in einigen Regionen bereits knapp geworden. Degradierung beeinflusst die landwirtschaftliche Produktion und somit die Existenzsicherung. Gesetze hinsichtlich Wasser sind eng verknüpft mit der Bodenbesitzstruktur und gleichermaßen betroffen von der Koexistenz gebräuchlicher Besitzstrukturregimes and modernen Gesetzen. Ländliches Wassermanagement ist besonders betroffen vom Versuch der Einflussnahme, unklarer Verantwortlichkeiten und dem Fehlen von Kompetenzen. Im Laufe des Dezentralisierungsprozesses der Wasserversorgung wurde das Management an die Kommunen übergeben. Die Schwierigkeiten, denen die Kommunen gegenüberstehen bei der wirksamen Erfüllung ihrer Verantwortlichkeiten, hängen eng mit der gesetzliche Unsicherheit zusammen. Viele Kommunen veröffentlichen keine statistischen Daten. Aus diesem Grunde wurde für diese Zielgruppe das IMPETUS Informationssystem LISUOC (Livelyhood Security in the Upper Ouémé Catchment = Existenzsicherung im oberen Ouémé-Einzugsgebiet) entwickelt, um statistisch repräsentative Daten zur Existenzsicherung, zu demographischer Entwicklung und zum Wassermanagement bereitzustellen.

Wasser beeinflusst in signifikanter Weise die menschliche Gesundheit. Beispielsweise ist Niederschlag maßgebend für die Entwicklung der Stechmücken und ermöglicht die Verbreitung von durch Mücken übertragenen Krankheiten wie Malaria in den Tropen. Durch Wasser übertragene Krankheiten auf Grund bakterieller und viraler Verunreinigung des Trinkwassers haben einen erheblichen Einfluss auf die menschliche Gesundheit. Informationssysteme wurden entwickelt, die zum einen den Einfluss von Klimaänderungen auf das Malariarisiko in Afrika abschätzen und die zum anderen am Oberlauf des Ouéme-Einzugsgebietes auf Dorfniveau Informationen über die Trinkwasserversorgung und –qualität liefern und somit dazu beitragen, Notfallsituationen bezüglich durch Wasser übertragener Krankheiten zu vermeiden.

Ergebnisse für Marokko:

Im mittleren Drâatal sind Aktivitäten, die Einkommen erzeugen, sehr stark auf Wassernutzung and Landressourcen gestützt. Dennoch tragen Arbeitsmigration und Tourismus zunehmend zur Diversifizierung der Einkommensquellen ackerbaulicher und pastoraler Haushalte bei. Die wichtigste Komponente des Wasserbedarfs im Drâatal ist der Pflanzenbau in den Oasen des mittleren Drâatals, was ohne den ausgiebigen Einsatz von Bewässerung nicht möglich wäre. Agronomische und ökonomische Optionen für das Bewässerungsmanagement wurden analysiert und simuliert. Aus der agronomischen Sicht wurden Schwerpunkte insbesondere auf Probleme temporärer Wasserknappheit und auf Probleme im Zusammenhang mit der zunehmenden Bodenversalzung als Konsequenz der ausgiebigen Bewässerung und Grundwassernutzung gesetzt. Mit Hilfe eines wasserökonomischen Simulationsmodells wurden die Konsequenzen der langfristigen Schwankungen in der Wasserversorgung simuliert. Im Gegensatz hierzu wird die Landnutzung von extensiver pastoralnomadischer Produktion dominiert. Die physikalische Biomasseproduktion von extensiv genutzten Weiden unter klimatischen Veränderungen wurde mit Hilfe einer an die örtlichen Bedingungen angepassten Version des SAVANNA Modells simuliert. Dieses räumlich explizite, prozessorientierte Modell simuliert räumliche Tierdynamik auf Grundlage der Verteilung von Biomasseproduktion. Darüber hinaus wurden die Resilienzmechanismen des pastoralnomadischen Weidemanagements im erweiterten Bereich des Drâatals untersucht. Die Mobilität der Viehhirten in der Region erlaubt die Bewahrung lokaler Futterquellen und verstärkt daher die Funktion der Weiden als ökologische Puffer gegen Schwankungen in der Umwelt. Entscheidungen hängen auch von sozioökonomischen Ressourcen und individuellen Netzwerken ab, die als ökonomische Puffer fungieren.

Wasserknappheit ist ein ernstes Problem in ariden und semiariden Flusseinzugsgebieten wie dem Drâatal in Südmarokko. Die Abschätzung möglicher zukünftiger Entwicklung der Wasserressourcen unter dem Einfluss des Globalen Wandels erfordert ein umfassendes Verständnis gegenwärtiger Prozesse des Wasserhaushalts. Aufgrund der Aufspaltung des Einzugsgebietes durch den Mansour-Eddahbi-Stausees in zwei eindeutige hydrologische Einheiten folgte die hydrologische Analyse dieser Unterteilung. Für die Wasserressourcen des oberen Drâatals, insbesondere für das Auffüllen des Stausees, sind die Berge des Hohen Atlas von entscheidender Bedeutung. Für die Vorhersagbarkeit der Schneeschmelze und daher das Auffüllen des Stausees wurden Fernerkundungsmethoden mit einem Modell der Schneeschmelze kombiniert. Zwecks Simulation der hydrologischen Prozesse für das gesamte obere Drâabecken wurde das Modellsystem SWAT angepasst und kalibriert. Eine Analyse beider Ansätze ergab, dass mit einem allgemeinen Rückgang der Oberflächenwasserverfügbarkeit bis 2030 gerechnet werden kann, aber es gibt keinen signifikanten Trend bei extremen Trocken- oder Feuchtperioden. Die Wasserverfügbarkeit im mittleren Drâatal hängt vom Oberflächenwasser aus dem Mansour-Eddahbi-Staussee und von der Grundwasserverfügbarkeit ab. Klimaänderungen werden die Wasserknappheit und die Bodendegradierung durch Versalzung verschärfen. Veränderungen bei Wassernutzungsstrategien werden die Ressourcen maßgeblich beeinflussen. Daher können angepasste Strategien die Folgen von Dürre abmildern. Um die verschiedenen Handlungsoptionen zu bewerten, wurden Entscheidungsunterstützungssysteme entwickelt, die das Wissen, die Modelle, die Daten und die im Projekt entworfenen Zukunftszenarien beinhalten.

In ariden Regionen ist Wasser eine schwer vorhersagbare natürliche Ressource. Landnutzung muss an die Verfügbarkeit von Wasser für Pflanzenwachstum und Trinkwasser angepasst werden. In den Oasen entlang des Drâa wird die Schwankung des verfügbaren Wassers teilweise durch natürliche Speicherung und durch Managementaktivitäten des Menschen gepuffert. Die weiten Flächen außerhalb der Oasen werden als Weideland genutzt. Hier können Wasserressourcen nur indirekt gemanagt werden über das Management der Vegetation und der natürlichen Ressourcen, Feuerholz und Grünfutter. Um die Auswirkungen des direkten und indirekten Wasserressourcenmanagements auf das Funktionieren des sozial-ökologischen Systems zu verstehen, müssen lokale Landnutzungsstrategien analysiert werden. In der Vergangenheit hat sich die Forschung auf das Management der Wasserressourcenknappheit konzentriert, da dies ein offensichtliches Problem des Managements natürlicher Ressourcen in ariden Gebieten darstellt. In dem vorliegenden Projekt wurde ein erweiterter Ansatz verfolgt und die relevanten Faktoren auf jährlicher und Jahr-zu-Jahr Basis analysiert. Es wurden Schlüsselmerkmale pastoralen Landmanagements im Bereich des Hohen Atlas identifiziert, die die negativen Auswirkungen extremer Wetterereignisse (Dürren und Überschwemmungen) abmildern und die Landdegradierung verlangsamen. Die Ergebnisse zeigen, dass lokale Landnutzung Dürreeffekte abmildert durch vorbeugendes Management der natürlichen Ressourcen, insbesondere in regenreichen Zeiten; es erhält oder erhöht die Fähigkeit der Weidelandvegetation gegen Niederschlagsvariabilität zu puffern.

Im Bereich Gesellschaft wurden lokale soziale Strukturen und gesellschaftliche Prozesse beleuchtet, die das Treffen von Entscheidungen hinsichtlich Existenzsicherung beeinflussen. Neben Strategien bezüglich des Managements natürlicher Ressourcen in der Region des Hohen Atlas im südlichen Marokko wurden insbesondere Prozesse des sozioökonomischen und demographischen Wandels im Einzugsgebiet des Drâa untersucht. Diese Prozesse werden direkt beeinflusst durch die kritische Verfügbarkeit von Wasser auf regionaler und lokaler Ebene. In diesem Kontext wurden Prozesse der Urbanisierung, Migrationsmuster sowie ethnische Zugehörigkeiten, sozialer Status Einzelner oder von Gruppen und ihre Auswirkungen auf wirtschaftliche Strategien analysiert. Arbeitsmigration zu den urbanen Agglomerationen im Norden des Landes und auch zu den regionalen urbanen Zentren nimmt ständig zu, was in ein relativ niedriges Bevölkerungswachstum in ländlichen Gegenden und in einen Anstieg der Urbanisierung resultiert. Geldüberweisungen von Migranten, die die wichtigste Einkommensquelle für die Bevölkerung in marginalisierten ländlichen Regionen darstellt, werden teilweise dazu verwendet, landwirtschaftliche oder pastorale Aktivitäten zu subventionieren und sind deswegen entscheidend für den Fortbestand des Agrarsystems.

Summary

The overarching goal of the third phase of the IMPETUS West Africa project was the development of decision support systems for local decision makers for the sustainable management of the limited resource 'freshwater' in two river catchments north and south of the Sahara: the wadi Drâa in southeast Morocco and the Ouémé river in Benin. The interdisciplinary and application-oriented task was accomplished with the help of a unique concentration of a high number of scientists both from the social and natural sciences. The scientific results achieved within the duration of the project entered the different decision support systems developed, whose successful implementation and operationalization within the partner organizations is the aim of the subsequent "Implementation Phase". In the following the most important results of the third three-year phase are summarized:

Developing a number of Spatial Decision Support Systems (SDSS) in a limited time is a challenge for software developers. To be as efficient and flexible as possible a SDSS Framework has been designed and implemented. The SMILE Framework tries to meet all partly contradicting demands like easy to use but offering complex functions. This java® based software tries to ensure a good adaptability, simple maintenance, wide capacity of integration of different models and tools, and a highly efficient development of the SDSS. The aim is to offer the possibility to developers and scientific users to concentrate on the scientific content of their work instead of getting perfect knowledge in programming languages.

Within the IMPETUS project about 30 different systems are developed within the SMILE Framework. The range of topics included in this integrated decision support framework (ISDSS) varies from a weather generator, integrated hydrological models to socio-economic systems. Target groups for the systems are governmental, scientific and non-governmental organizations within Benin and Morocco.

Results for Benin:

Food security in Benin Republic is threatened, among other factors, by soil fertility degradation which is caused and influenced by a number of driving forces e.g. demographic pressure, education and fertilizer policies. Ongoing adaptation strategies to cope with soil degradation, which is most pronounced in the densely populated areas, are improved fallow systems, exploitation of inland valleys and increasing use of mineral fertilizers. In a joined effort with national institutions, inland valleys have been inventoried and an information system has been developed to facilitate the access to the data and to evaluate the potential (BenIVIS: Benin Inland Valley Information System). The effect of fallow systems and fallow availability as well as fertilizer use and climatic changes on soil fertility degradation and crop yield can be assessed with the spatial decision support system PEDRO (Protection du sol et durabilité des ressources agricoles dans le bassin versant de l'Ouémé). Simulation runs based on climate scenarios until the year 2050 indicate a decline in crop yields due to a projected decrease in rainfall. This will add to the ongoing problem of soil fertility degradation in the Upper Oueme basin. Economic evaluation of changing fertilizer policy using the BenIMPACT model shows that the profitability of the application

of mineral fertilizer is still precarious, preventing sufficient levels of utilisation to stabilise soil fertility, land use, and food supply. Labour is still too cheap to reward labour-saving technical innovations. As long as slashing forest is still cheaper than using fertiliser to arrive at the same yield level, little change of current trends can be expected. Sustained higher economic, income, and wage growth would, other things kept equal, contribute a lot to reverse current trends of excessive transformation of natural savannah into cropland and threatened food security in Benin.

Balancing future water availability and water demand as well as estimating future soil degradation requires a thorough understanding of natural processes and social conditions as well as plausible scenarios of future economic, demographic, and climatic developments. To estimate future water availability, the output of a regional climate model was linked to a hydrological model that also considers land use changes as projected by a cellular automata model. Future water requirements were computed by combining trends in population growth and per-capita water demand, the latter was estimated based on a regional survey among private water users. Furthermore, the water demand for animal husbandry, irrigation, and industry were considered. Water availability is subject to high temporal variation due to the natural inter-annual sequence of rainy and the dry seasons. And even if physical water scarcity does not appear to represent the most important limiting factor, access to water in some parts of the catchment is constrained by low economic capacities of suppliers and users. Soil degradation by water erosion is computed using the model system SWAT and the scenarios mentioned before. Both, climate and land use change will influence soil erosion in opposite directions but land use change will dominate future development. The analysis reveals a large inter-regional disparity with hot spots of soil degradation and water scarcity. The results and models discussed here are implemented in Decision Support Systems which may help decision makers to evaluate the effect of different options for action.

Land-use and land-cover is a critical ecosystem component, and changes in land-use and land-cover have definite and predictable impacts on climate, hydrology, biodiversity, and biogeochemical cycles. In Benin, land-use and land-cover changes will happen at high rates, mainly because of a doubling in the population within the next 30 years. In order to estimate the recent and future land-use and land-cover changes, the remote-sensing-based regional Land Use Model and Information System LUMIS was developed. LUMIS is a spatially explicit, raster-based land-use and land-cover change model. Based on a logistic regression approach, land-use changes are driven by a set of natural, demographic, economic, and cultural factors. The parametrization of LUMIS was performed for the period of 1991 to 2002, when detailed ecological and socio-economic data were available. The model accuracy can be classified as medium-to-high, with an area-under-curve value between 0.7 and 0.9. The results show that population density and the distance to the road are the dominant driving forces for the conversion of natural savannah areas into agricultural land. Using the IMPETUS land-use scenarios B1 (*economic growth*), B2 (*economic stagnation*) and B5 (*intervention*), future land-use changes (until the year 2025) were calculated, and the possible consequences on water availability and food security were analyzed. While the B1-scenario shows a reduced loss of forest land for agriculture, the B2-scenario is characterized by a high deforestation rate. Furthermore, both scenarios show an increased settlement growth, either caused by positive economic development with an increasing number of off-farm jobs in the cities (B1) or by a high rural-urban migration rate, with more and more people moving into the vicinity of the cities in search of work (B2). Land-use and land-cover change modeling using LUMIS can be of particular utility in identifying and monitoring the critical development of ‘Hot-Spots’. LUMIS enables the early detection of land-use and land-cover changes as well as of planning effective measures to counter such changes.

Management of natural resources in Central Benin is undergoing considerable change. Recent modifications in land tenure and water supply management are taking place in close connection with processes of decentralization, democratization, and new policies. Customary tenure principles are highly dynamic and vary from one place to another. The conflict between these socially embedded traditions and national land legislation requires the coexistence of modern and customary land rights, legal pluralism, and legal uncertainty. Land disagreements emerge, the purchase of land is problematic and property rights are unevenly distributed. In additon, land has already become scarce in some parts of the region. Degradation affects agricultural production and, therefore, the security of livelihood. Laws regarding water are closely related to land tenure and similarly affected by the coexistence of customary land tenure regimes and modern law. Rural water management is particularly affected by a struggle for influence, unclear responsibilities and lack of competencies. During the course of the decentralization process of the water supply, management has been delegated to the communities. The difficulties these communities face in effectively meeting their responsibilities are closely linked to legal uncertainty. Many communities do not release any statistical data. Hence, the IMPETUS Information System LISUOC (Livelihood Security in the Upper Ouémé Catchment) has been developed for this focus group to provide statistically representative data on livelihoods, demographic development, and water management.

Water significantly influences the health of humans. Rainfall is, for example, essential for mosquito breeding and enables the spread of mosquito-borne diseases like malaria in the tropics. Waterborne diseases caused by bacterial and viral contamination of drinking water have a substantial impact on human health. Information systems were developed that (a) assess the impact of Climate Change on malaria risk in Africa and (b) provide information at the village level in the Upper Ouémé catchment on drinking water supply and quality, thus helping to prevent cases of emergency of waterborne diseases.

Results for Morocco:

The income-generating activities in the Middle Drâa Valley are strongly based on water use and land resources. Nevertheless, labor migration and tourism increasingly help to diversify the sources of income for farm and pastoral households. The most important component of water demand in the Drâa basin is crop production in the oases of the Middle Drâa Valley, which would be impossible without the extensive use of irrigation schemes. Agronomic and economic options for irrigation water management are analyzed and simulated. From an agronomic perspective, specific emphasis is put on problems of temporal water scarcity and on problems with increasing salinization of soils as a consequence of irrigation water use and groundwater mining. Using a hydro-economic simulation model, the consequences of long-term trends in the volatility of water supply are simulated. Land use, by contrast, is dominated by extensive pastoral-nomadic production. The physical biomass productivity of extensive pasture under climate change is simulated using a locally adapted version of the SAVANNA-Model. This spatially explicit, process-orientated model simulates spatial animal dynamics based on the distribution of biomass productivity. In addition, we look into the resilience mechanisms of pastoral-nomadic range management in the wider Drâa region. Pastoralists' mobility in the region allows for the preservation of local fodder resources, thus enhancing the function of pastures as ecological buffers against environmental variability. Decisions also depend on socio-economic resources and individual networks, which function as economic buffers.

Water scarcity is a severe problem in arid and semi-arid catchments like the Drâa basin in Southern Morocco. Estimating possible future development of water resources under Global Change requires a thorough understanding of the current processes and the water balance. As the Mansour Eddahbi reservoir splits the catchment into two distinct hydrological units, the hydrological analysis follows this subdivision. For the water resources of the Upper Drâa valley, especially the reservoir filling, the High Atlas Mountains are of crucial importance. To be able to forecast snow melt and therefore reservoir filling remote sensing techniques were combined with snow melt modelling. To simulate the hydrological processes for the whole Upper Drâa basin the model system SWAT was adapted and calibrated. The analysis of both approaches reveals that a general decline in surface water availability can be stated until 2030 but there is no particular trend for extreme dry or wet periods. Water availability of the oases in the Middle Drâa valley depends on surface water (Mansour Eddahbi reservoir) and groundwater availability. Climate change will lead to enhanced water scarcity and soil degradation by salinization. Changes in water use strategies will influence the resources significantly. Thus adapted measures can mitigate drought effects. To allow evaluation of different options for action, Spatial Decision Support Systems are developed which comprise the knowledge, the model, the data and the scenarios developed in this research project.

In arid environments, water is a highly unpredictable natural resource. Land use must be adapted to the availability of water for plant growth and as drinking water. In the oases along the river Drâa, the variability of available water is partly buffered by natural storage and by human management. The vast areas outside the oases are used as rangelands. Here, water resources can only be managed indirectly, through the management of the vegetation and natural resources, firewood, and forage. To understand the effects of direct and indirect water resource management on the social-ecological system's functioning, local land use strategies must be analyzed. In the past, research has concentrated on the management of water resource scarcity because this is an obvious problem of natural resource management in arid regions. In this project, we applied a broadened approach and analyzed the relevant factors on an annual and inter-annual scale. We identified key traits of pastoral land management in the High Atlas region that mitigate the negative effects of extreme weather events (droughts and floods) and slow down land degradation. Our results show that local land use mitigates drought effects through a preventive natural resource management, particularly in times of abundant rainfall; it maintains or increases the capacity of the rangeland vegetation to buffer against rainfall variability.

This section highlights some key elements of local social structures and societal processes that influence decision-making to secure peoples' livelihoods. Besides strategies related to natural resource management in the High Atlas region of southern Morocco, particular stress is laid upon processes of socio-economic and demographic change in the Drâa Catchment. These processes are directly influenced by the critical availability of water on a regional as well as a local scale. In this context, the process of urbanization, patterns of migration as well as ethnic affiliations, social status of individuals or groups and their effects on economic strategies are analyzed. Labor migration to the urban agglomerations in the north of the country, and also to regional urban centers, is continuously growing, resulting in both relatively low population growth in rural areas and in increasing urbanization. Remittances from migrants, as the most important source of income for the population in the marginalized rural regions, are partly used to subsidize farming or pastoral activities and are therefore crucial for the continuity of the agricultural system.

I. Einleitung / *Introduction*

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

Motivation

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

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

Choice of catchments

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

Between the Atlas Mountains and the Gulf of Guinea (Fig. I.1) two reasonable sized river catchments were chosen along a transect according to the following criterias: feasibility (< 100.000 km^2), availability of pre-existing data sets, political stable conditions, relevance and representativeness in the following sense: the Drâa catchment in the south east of Morocco is typical for a gradient from humid/sub-humid subtropical mountains to their arid foothills; the Ouémé basin in Benin is typical of an alternating sub-humid climate (“Guinea-Soudanian”) of the outer tropics embedded within a transect from the Sahelian to the Guinean Coast climate.

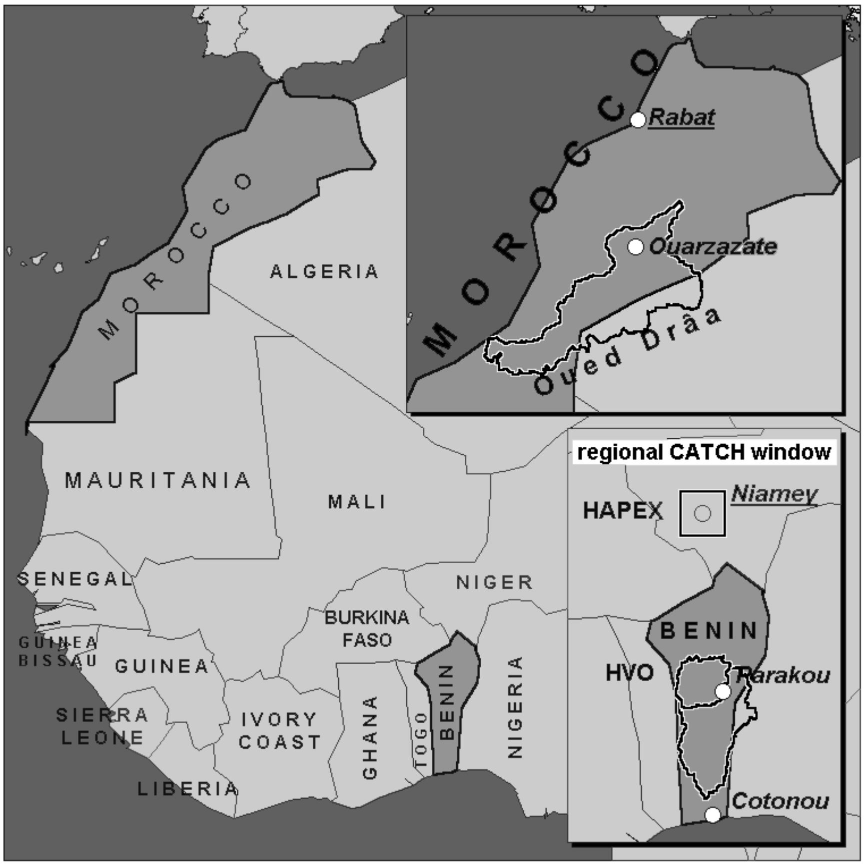

Fig. I.1: The two river catchments of consideration: The DRÂA catchment in Morocco and the OUÉMÉ catchment in Benin are boldly bordered.

<u>Past and present situation</u>

Moroccan precipitation is strongly related to the large-scale atmospheric circulation over the subtropical and extra-tropical North Atlantic and the Mediterranean Sea, with the bulk of precipitation occurring in winter between November and March). Since the late 1970s, Morocco has experienced a number of extremely dry winter seasons, the causes of which are not fully understood. Against this background, the development of sustainable water resource management is even more a necessity. The considered wadi Drâa possesses two main tributaries, the wadi Dades and the wadi Ouarzazate which drain the south-eastern and the south-western parts of the Atlas and confluence near the city of Ouarzazate thereby forming the wadi Drâa. At the site of confluence construction of a storage lake was completed in 1972 with an original storage capacity of 560 million m^3. Due to strong sedimentation a capacity of only 440 million m^3 remains today. Approximately 250 million m^3 of stored water is released in normal years for irrigation purposes. The irrigated perimeter covers a total area of approximately 26.500 ha. Since the snow melt in spring contributes significantly to the annual discharge of the main storage lake tributaries, diagnosing the spatial distribution of accumulated snow water equivalent in the elevated areas of the catchment is particularly desirable. An effective and sustainable management of water in the Drâa valley is essential to enable the competing users (water power generation, irrigation, domestic consumption) to have adequate supplies, and to prevent social tensions related to water resources.

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

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

<u>Concept</u>

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

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

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

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II. Die räumlichen IMPETUS-SDSS / *The IMPETUS Spatial Decision Support Systems*

II.1 Entscheidungsunterstützung / *Decision Support*

The definitions of Decision Support Systems (DSS) or Spatial Decision Support Systems (SDSS) are manifold. In this study we use the following:

Decision Support Systems (DSS) are interactive and flexible computer based systems (Densham 1991). They are used to identify and solve complex, poorly structured problems hereby improving the decision-making process (Turban et al. 2004). Following Matthies et al. (2007) they should focus on the specific needs of users and should be developed in an interactive process. Therefore it is necessary, that such systems contain data and tools needed to support the decision process with regard to this target group of end users.

A SDSS (Manoli et al. 2001) differs from a DSS concerning the spatial aspect which plays a decisive role in the decision support process. The use of spatial data increases the accuracy of the deduced decisions (Crossland et al. 1995). A SDSS consists of

- a spatial database containing all data, in parts spatially referenced, used in the decision process. Shim et al. (2002) explains the necessity of interchange of this database via internet and foresees the development of SDSS interacting via data exchange,
- the scientific models using and producing data,
- a toolbox containing features from a geographic information system and further tools that enable the system to analyse and interpret the results,
- a Graphical User Interface (GUI) bridging between user and computer system.

Often the system developers define their view on (S)DSS without considering what exactly is demanded by the target group, the scientific discipline, or the societal circumstances. Following Uran and Janssen (2003) this is one of the main points why DSS are often not used or not maintained after the end of a project. The following aspects have to be considered during the development of SDSS (Enders & Diekkrüger, 2009):

1. Project aspect: What is the need of the (IMPETUS) project regarding the individual aspects of decision support?
2. General aspect: With which requirements is a SDSS confronted in general?
3. Organizational aspect: What and whom do we need to successfully implement and introduce a SDSS? Who has to communicate with whom regarding the development and implementation of the system? How has this communication to be supported?
4. Societal aspect: What is the demand of the users – who is the target group?

5. Scientific aspect: Which are the functions needed for the different systems? Which functionality assures the scientific correct preparation, implementation and presentation of the systems?
6. Technical aspect: What are the technical standards to meet? Are there specific technical requirements of the target group to take into account?

Considering all aspects in the development of SDSS software it is clear, that many requirements are or seem to be contradictory (Matthies et al., 2007) (see Tab. II.1). The aim of the software development within the IMPETUS project was to unravel these contradictory requirements to allow the decision support to be complex but easy to use.

Table II-1: Examples for inconsistency of requirements on SDSS.

Autonomy of a system	Integratibility of systems
Simple manipulation of data and parameters	Complex functioning
Flexibility in function and configuration	Simplicity in development
Reusability	Individuality of solution
Good usability	Diversified actions possible
Fast development	Sophisticated function
Licence fee free software	Recent top-level features

II.2 IMPETUS SDSS Framework / *IMPETUS SDSS framework*

In the IMPETUS project the challenge was to develop numerous information systems, monitoring tools as well as spatial decision support tools within short time. The high number of systems was due to the large number of interests, topics, stakeholders, etc. To develop standalone systems independent of each other would not utilize synergies and would require more time for programming. Therefore, to develop and integrate all different SDSS, IS, MT a Framework has been designed and programmed. The SMILE (Scientific Model Integration pipeLine Engine) Framework meets the requirements mentioned before and aims to facilitate software development by allowing SDSS developers to spend more time on meeting SDSS requirements rather than dealing with the more standard low-level details of providing a working system. Software frameworks are well known in DSS development. Often the term ‘DSS Generator’ is used for the same matter.

II.3 Struktur des SMILE Frameworks / *Structure of the SMILE Framework*

The SMILE Framework (Fig. II.1) contains all modules for accessing database and scientific models, geographic operations, result presentation and rich client architecture to meet the requirements of the SDSS. The Framework is designed to be used in different environments and projects with completely different general conditions. For implementing a SDSS it is not necessary to use the development language java® as the XML language is applied. The SMILE Framework incorporates also a server based version that is compatible with the standalone client version.

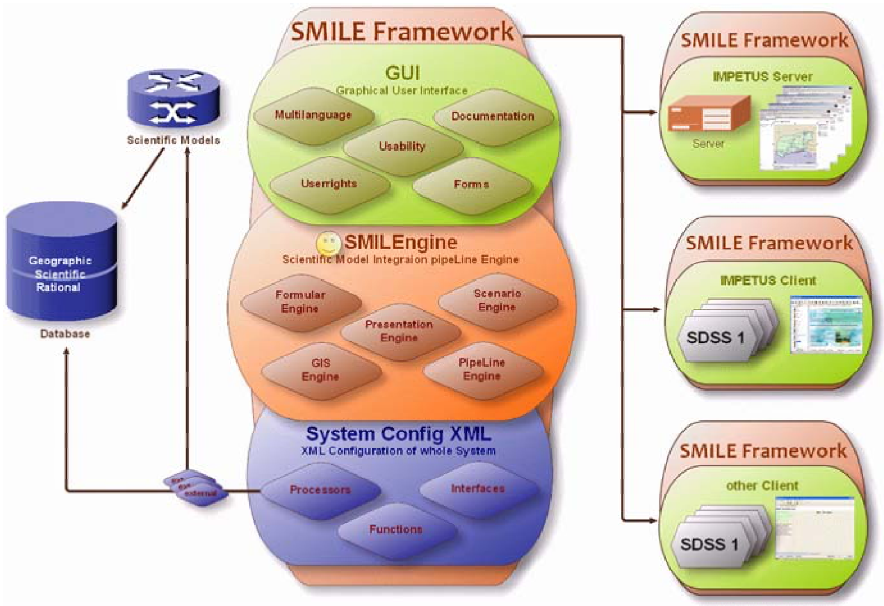

Fig. II.1: Component based structure of the SMILE Framework.

II.4 GUI – Graphische Schnittstelle / *GUI – Graphical User Interface*

The user interface is designed to be both easy to use and secure in data management. The system developer can specify exact constraints to the parameterization if required. The functionalities allow the user to have both – simplistic use and complex function (cf. Fig. II.2). Forms are created by arranging different form components in one view. All components are able to directly react on each other's changes. The created data is forwarded to the pipeline using java object design to be transported from one component each other. The documentation part is directly linked to the functionalities. One can choose between documentation resources in the internet, in the form of PDF or the Framework integrated html. The user has the possibility to browse the IMPETUS Atlas application (geopublishing.org) that is fully integrated into SMILE Framework and provides geo-referenced maps. Finally the GUI is enabled with the java standard multilingualism concept.

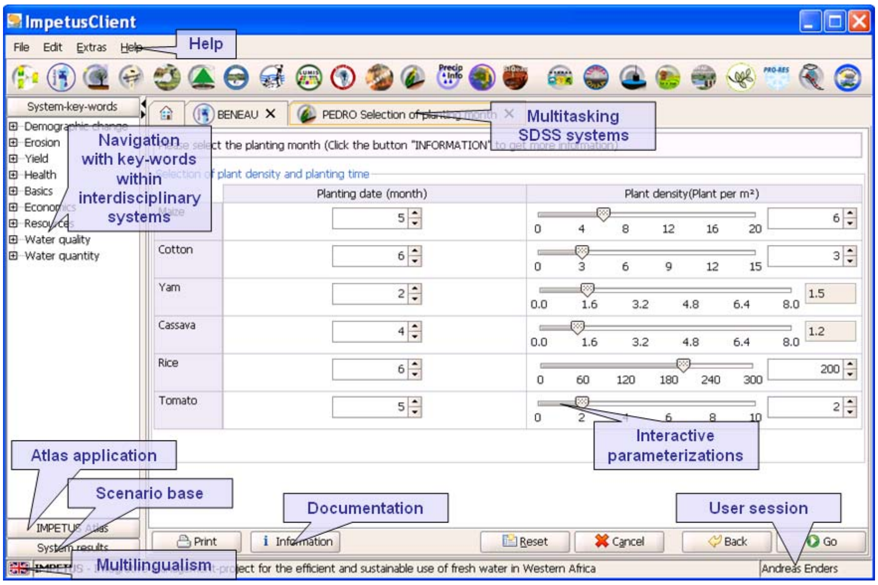

Fig. II.2: GUI of IMPETUS Client created with SMILE Framework.

II.5 SMILEngine – Scientific Model Integration pipeLine Engine / *SMILEngine – Scientific Model Integration pipeLine Engine*

The SMILEngine is the core of the Framework. It combines features for automating the decision process without impairing the user interacting possibilities. The Formula Engine provides interactive transport, print and availability of data, the GIS Engine supports the systems with sophisticated GIS features, the Scenario Engine provides the system with a build in result data storage for comparing and interchanging results, the Pipeline Engine rules the step by step organization without eliminating possibilities of multitasking and parallel computing, and the Presentation Engine signifies a performing presenter for result data including diagrams, tables, maps, html or pdf information in an interactive way (see Fig. II.1).

II.6 XML-Konfiguration / *Configuration XML*

The client configuration XML enables the SDSS developer to easily develop a system without or with very rare knowledge in programming language. He can configure whole systems using the SMILE specific grammar using XML standards.

Using the experience of the IMPETUS project a normal skilled scientist can develop own simple SDSS or IS after short training. The grammar of the XML configuration is automatically checked providing code completion.

The implementation of extended features like external models, new form components, functionalities or background processors is possible by overwriting an abstract class. In this way, besides the core featured Geotools (Macgill 2005) framework, the ArcGIS Engine (ESRI®) has been attached by Laudien (2008). The implementation of scientific models is possible in various prepared ways that generally only demand XML configuration:

1. Integration is done by interfacing the configuration, execution and import of results – mostly used for software written in FORTRAN, PASCAL, etc. The analysis of results is done with the help of the integrated rational database Hypersonic SQL.
2. Integration by using Excel® (Microsoft Corporation) as data source and/or model implementation.
3. Full integration by creating SMILE Processors interacting with the Hypersonic SQL or native implementations.

With this integration technique there are a great number of background processors prepared like file system management, database management, GIS, ASCII-file management, Excel® spreadsheet management and model management. There are rich featured interfaces created for models used in IMPETUS like CLUE-S (Verburg et al. 2002), EPIC (Williams et al. 1983), SWAT (Arnold and Fohrer 2005), UHP (Bormann and Diekkrüger 2004) and others.

II.7 Entwicklung von SDSS / *Development of Spatial Decision Support Systems*

In total 10 decision support systems, 11 information systems, and 2 monitoring tools have been developed and implemented into the SMILE Framework. An overview is given in Tab. II.2 for Benin and in Tab. II.3 for Morocco. In addition to the mentioned systems the IMPETUS atlas is implemented which allows easy selection and presentation of spatial data, graphs as well as documents.

Table II.2: Benin related decision support systems, information systems, and monitoring tools implemented into the SMILE Framework.

Acronym	**Title**	**Short description**
BenImpact	BenImpact scenarios for land use and food supply	IS for visualizing scenarios and analyses of the BenImpact Agricultural Sector Model dealing with agricultural land use and food supply.
PEDRO	Assessing soil degradation and crop yield in the Upper Ouémé catchment	SDSS for investigating the impact of changes in climate, land use and crop management on soil degradation and crop yield in the Upper Oueme catchment until 2025.
ClimModInfo	ClimModInfo – Informations about Climate Modeling	IS for explaining the background of climate modeling on the one hand and the work with climate models in the IMPETUS project on the other hand.
AGROLAND	Natural and socio-economic conditions for a sustainable agricultural land use	Expert model; Evaluation of land resources for sustainable agricultural land use under Global Change
BenIVIS	Inland-Valley Information System for Benin	IS to analyze the Agro-Potential of Inland-Valleys in the Upper Ouémé Catchment
LISUOC	Livelihood Security System in the Upper Ouémé Catchment	IS on livelihood security regarding demographics, work (production, consumption, distribution), capital, risk strategies, health
MalaRis	Impact of climate change on malaria risk in Africa	SDSS for simulating the spread of malaria in Africa by the Liverpool Malaria Model enables the malaria risk assessment during the observed and projected climate change.
SIQeau	Supply and quality of drinking water in rural Upper Ouémé catchment	IS on the statuts of the drinking water in the Upper Ouémé catchment; highlighting risks, options on the prevention of water-borne diseases and measures in case of emergency
BenHydro	Water availability and water consumption in the Ouémé catchment	SDSS to analyze water availability and water consumption in the Ouémé catchment considering socio-economic and environmental changes.
BenEau	Domestic, industrial and agricultural water demand in Benin	SDSS to analyze the domestic, industrial and agricultural water demand in the course of Benin's socio-economic developments as well as climate/environmental change.
PrecipInfo	IS concerning rainfall distribution in Benin	MT for real time assessment of rainfall using satellite data
LUMIS	Land use modelling and Information System	LUMIS is a spatial explicit information and modeling system. It provides information about land cover and land use and is able to model future scenarios of land cover and land use change.
ILUPO	Impetus - Land Use Change and Precipitation for the Ouémé area	Provision of recombined time series of precipitation and evaporation with the model FOOT3DK by means of IPCC scenarios (SRES). Horizontal resolution is 3 km and the time step is one hour.
FARMADAM	Farm adaptation management to water availability	IS for the „eco-volume“ for all districts presenting the results for different land use types like annual crops, fallow, savannah, and perennial crops and forest

Table II.3: Morocco related decision support systems, information systems, and monitoring tools implemented into the SMILE Framework.

Acronym	**Title**	**Short description**
MIVAD-SDSS	Water distribution in the Drâa valley	SDSS compiling and visualizing results of the simulation model MIVAD dealing with economic aspects of water management in the Drâa valley
HYDRAA	Hydrologic model for the Drâa catchment	SDSS quantifying natural and anthropogenic influences on water availability
IWEGS	Interaction between water use and groundwater and soil conditions in the middle Drâa Valley	SDSS supporting decisions on investigations concerning groundwater availability and soil salinity in the Drâa oases.
PRO-RES	Prognosis of snowmelt runoff for a water reservoir	MT calculating inflow to and the filling level of the reservoir using a snowmelt runoff model based on satellite images and a weather generator.
IDEP-DRÂA	Possible future Developments of Evaporation and Precipitation for the Drâa valley	The IS dealing with the future developments of evaporation and precipitation for the Drâa Valley
LUD-HA	Local Land use Decisions - High Atlas	Local land use decisions and strategies under the condition of limited water resources in the High Atlas
PLANT	Plants of the Upper Drâa valley	Information system for botanical, anthropological and ecological data
SEDRAA	Scenarios of soil erosion in the Drâa region	Assessment of soil erosion risk under changing climatic and land use conditions
SMGHydraa	Statistical model for the generation of meteorological data for hydrological modeling in the Drâa region	Climate data from IMPETUS climate scenarios are prepared for subsequent models.

II.8 Beispiel eines SDSS / *Example of a Spatial Decision Support System*

The aim of implementation of the SDSS, IS and MT is in general to transfer knowledge, data and models to the partners to support the decision making process in the field of water related problems. While it is not possible to present all 30 systems as an example the SDSS **Pedro – SDSS for estimating erosion and crop production at the regional scale using the integrated models SWAT and EPIC** is briefly described.

Aim of PEDRO

The population dynamic in the sub-humid savannah of Benin is characterized by fast demographic growth including migration from the densely populated southern departments. The high pressure on the natural resources is reflected in high deforestation rates, loss of soil fertility, and conflicts concerning water and land as food production has to satisfy the growing demand. Future climate change may aggravate the problem. National and local authorities are concerned with the issue of food security and economic development without compromising the natural resource base.

The SDSS Pedro has been developed to assist decision makers to identify strategies to reduce soil degradation as well as to improve food security. The objective of the SDSS PEDRO designed for the Upper Ouémé valley, Benin, is to assess the combined effects of changes in climate, land use and crop management specified by the user on the following target indicators:

- Annual and monthly discharge from 121 sub-catchments
- Annual sediment load from 121 sub-catchments
- Soil erosion
- Crop yield and biomass production of major crops
- Nutritional value of food production.

Application

The large range of target indicators requires the application of two complementary models: The hydrological and erosion model SWAT and the agro-ecological model EPIC (Fig. II.3). The model consists of the semi-distributed hydrological model SWAT which is designed for the regional sale (Soil water Assessment Tool, Arnold & Fohrer, 2005) and the field scale agro ecosystem model EPIC (Environmental Policy Integrated Climate, Williams et al. 1983) linked to the land resources information system SLISYS-Ouémé (Soil and Land Resources Information SYStem). Both models compute similar processes, but with different approaches and on different scales. In PEDRO, the first three indicators are calculated by SWAT whereas the EPIC model calculates the last three. Soil erosion is calculated by both models but due to the scale problem only SWAT is able to consider depositional processes. The output is either mean value over the entire basin or over the 121 sub-catchments (Fig. II.4). The SDSS PEDRO is composed essentially of four components: (1) the database (2) the user interface (tool base) (3) the numeric models (model base) and (4) the database of the output (result base) (Fig. II.3).

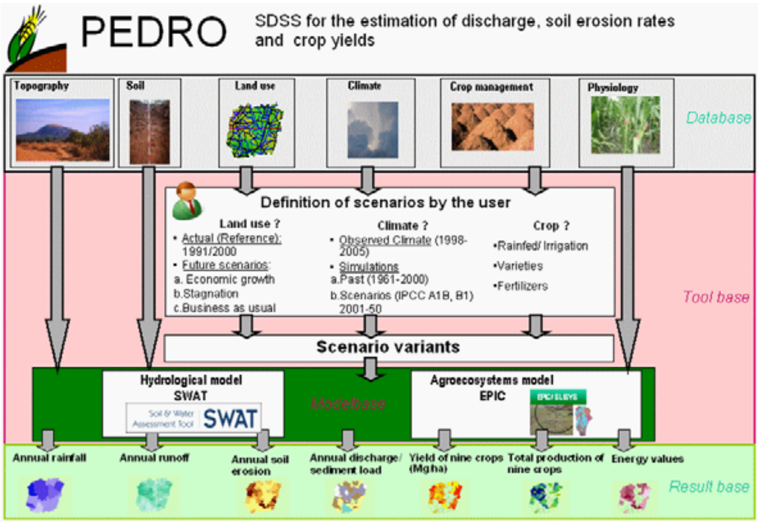

Fig. II.3: The components of the SDSS PEDRO.

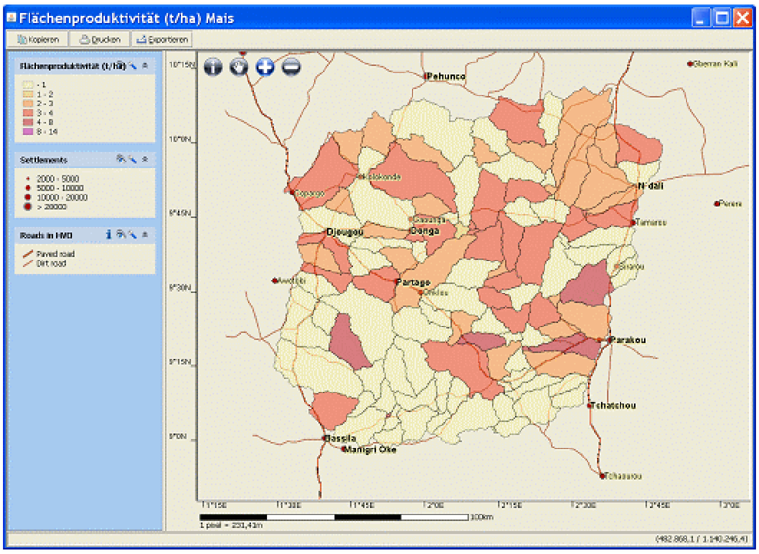

Fig. II.4: Subdivision of the Upper Ouémé catchment as used by the SDSS PEDRO.

The input database contains the specific data necessary to run the two simulation models SWAT and EPIC. With the use of forms the user can select a combination of input data (meteorological time series, different land use scenarios) as well as the duration of the simulation. This input can be combined with different management options to be defined by the user. The combination of a meteorological time series with a land use scenario and certain crop management options constitutes a COMBINED SCENARIO or SCENARIO VARIANT. The scenario variants determine the boundary conditions for the simulations with the models. The output of the simulations is then transferred to the result database and can be retrieved by the user through the interface as tables, figures or maps. The simulations are based on a number of input data like topography, soil properties, climate, land use, crop management, and crop parameters.

The system offers the choice to either select a predefined or newly define a setup concerning climate, land use and crop management. The user configures the system with a series of forms within the form engine of the SMILE Framework. The parameters for the model runs can be defined by the user and made available to the model through the pipeline engine.

The user defines scenario variants which are a combination of climate and land use scenarios, selection of crop varieties, irrigation type, irrigation frequency, water availability for irrigation, planting month, planting density, fertilizer timing and application rate. Theoretically about 3000 combinations are possible for e.g. maize cropping. Therefore, after having defined a specific combination of options (scenario variants) the user has to label it with a unique scenario name. In addition, he should provide a detailed description of the scenario variant.

The model runs are controlled by the SMILEngine. It guarantees that the runs for the user-defined scenario variants are carried out in a sequential order. After each run, selected output variables are automatically extracted from the model output files by a java coded wrapper and transferred into a fully java compatible SQL database (HSQLDB). Then the run of the subsequent scenario variant will be performed. Finally, the results are transferred into the scenario database.

Results

After finishing the calculations of the defined scenario variants, the user is forwarded to the result section of the IMPETUS SDSS client. The user can retrieve the results related to the target variables (see above) via the user interface.

In view of the large quantity of output parameters, the interface presents mean values over several years (often per decade) (Fig. II.5). First, the user can select the desired indicator in a combo box. If the indicator is related to agricultural production, he should select the preferred crop in a second combo box. Afterwards a choice between three types of presentation options (Figures, Tables, and Maps) is required. The option “Map” can only represent one scenario at the same time, whereas for the other presentation types the results of several scenarios can be displayed simultaneously. Nevertheless, the user is able to open numerous maps for comparing the results.

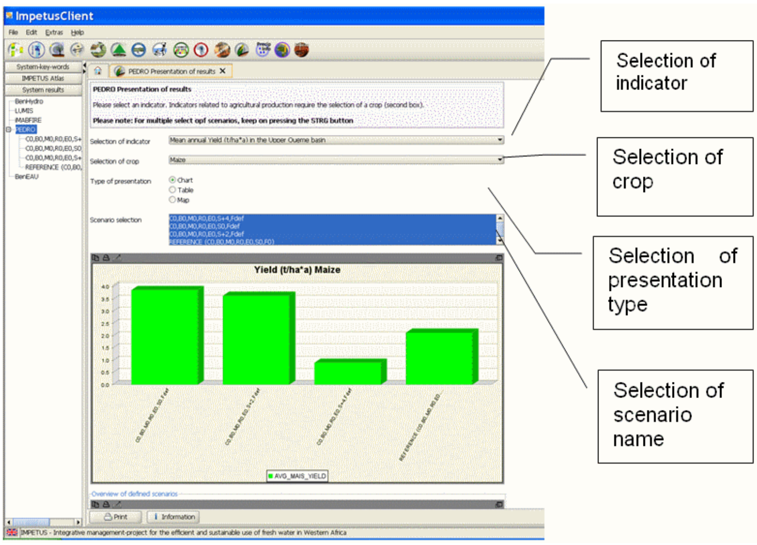

Fig. II.5: Selection of scenario variants and their target indicators in the results database of the SDSS PEDRO.

The map presentation can be enriched with additional spatial layers of the IMPETUS Atlas, which facilitates the localisation of objects on the maps. This is performed by opening the IMPETUS Atlas in the explorer window on the left hand side of the main window and to move the desired layer by a “Drag and Drop” action from the atlas into the map window which shows the results of the simulation.

From the scientific point of view the system PEDRO is a very complex system. Combining different models with different aspects of the natural environment is challenging. PEDRO manages the complex procedure of these coupled models transparent to the user and, therefore provides the decision makers with a tool which help evaluating effects of management strategies on crop production as well as soil degradation.

Conclusions

The successful implementation of 10 SDSS, 11 IS and 2 MT in cooperation with about 35 scientists from different disciplines shows that the main requirements concerning technical, project and scientific aspect have been met, although they are very contradictory. Various decision structures have been implemented, mostly by coupling different numerical models. The scenario base is successfully used by a number of SDSS systems which means that the development of this tool was advantageous.

Within the IMPEUTS DSS, developers tried to meet the requirements as close as possible. Nevertheless, a sustainable use of the SDSS systems can not be guaranteed by the developers and project leaders. Strategies to minimize the transition effects after the end of the projects are required. To guarantee sustainable use of the systems a close cooperation between the members of the expert group which consists of scientists, stakeholders and developing agencies is indispensable. This cooperation has been arranged during the project.

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III. Szenarien / *Scenarios*

In order to investigate the effects of Global and Regional Change on water resources and related issues, it is mandatory to develop a targeted, sound and foresighted environmental assessment at appropriate geographic scales. This assessment must integrate social, technological, environmental, economic and demographic issues. Scenarios that include expected developments in agriculture, economy, demography, and environment have become a state-of-the-art tool in environmental assessment and management (e.g., Gaiser et al., 2002; Millennium Ecosystem Assessment of UNEP (UNEP 2005); Alcamo 2008). Scenarios are consistent and plausible images of alternative futures that are comprehensive enough to support decision-making. Scenarios are not predictions or forecasts, but alternative development routes of complex systems. They enhance the information basis for decision-making through identifying the following: (1) the most important driving forces at the national and regional level; (2) sub-regional developments or events that are of national relevance; (3) the most important inter-linkages between national and regional development; and (4) the most important knowledge gaps and unanswered questions, which point to further actions needed. A meaningful scenario analysis must estimate a certain range of plausible developments that will enable decision-makers in public policy or private entities to deduce suitable advice from the results.

III.1 Methodik der IMPETUS-Szenarien / *Methodology of the IMPETUS Scenarios*

General definition of scenarios

Scenarios are usually a combination of qualitative and quantitative analyses that arise from the given differences between the scientific disciplines involved. While the natural sciences have a set of already existing numerical models to quantify driving forces, the social sciences, for example, give an interpretation of place-based analyses of human motivations. The use of models provides greater precision, rigor and consistency with explicit assumptions and conclusions, but in the qualitative part, representing those processes for which little or even no numerical data are available, human motivations, values and behavior can be incorporated. Therefore, scenario analyses must integrate disciplines across disciplinary frontiers. Scenario developments commonly consist of the following steps:

1. Generation of qualitative storylines describing the general societal, economic and ecological characteristics and their main driving forces, but also the degree of their mutual interaction. The special and temporal scales for which the scenarios are valid must be defined. Ideally, a range of alternative scenarios, so-called ‘base scenarios,’ are developed. Stakeholder participation is a prerequisite in all, but especially in this first phase, because it is necessary to pinpoint the most pressing issues in the targeted area.
2. Quantification of the driving forces and simulation of the impacts, quantified by response indicators.

3. Generation of ‘intervention scenarios.’ These take the scenarios developed in steps 1 und 2 as base or reference scenarios. They are then used to analyze the influence of certain external events (e.g., war, economic crisis), policies, programs or single measures of the system under investigation.

Scenario analysis depends heavily on the selection of appropriate driving forces. A driving force (or a driver), in the definition of Carpenter et al. (2005), is "any natural or human-induced factor that directly or indirectly causes a change in an ecosystem." Furthermore, Carpenter et al. (2005) distinguish between direct drivers and indirect drivers. While direct drivers, like climate change, definitely influence ecosystem processes, indirect drivers of change, such as demography, economy, technology and culture, operate more diffusely.

Definition of alternative scenarios and sub-regions within IMPETUS

The IMPETUS scenarios are based upon different assumptions about the way in which water resources in the catchments will develop in the future. In order to provide a broad range of potential future developments with respect to water resources and related issues, two so-called ‘reference scenarios’ were developed that reflect more extreme, yet realistic, development paths. In a third reference scenario, the current trends persist. Following Carpenter et al. (2005), climate change is treated as an external direct driving force (see Chapter III.2). It is, therefore, not explicitly included in the societal, economic and ecological scenarios (see Chapter III.3). Instead, a combination of both climate scenarios and socio-economic scenarios brackets the broad range of plausible futures.

Often, strong spatial inhomogeneities in demographic, economic and natural framework conditions found in a specific target region requires wisdom in dividing them into sub-regions, for which individual scenarios are then developed. If possible, this division should not cut across administrative boundaries.

Within the framework of IMPETUS, the research area in Benin, which covers most of catchment area of the Ouémé river, has been divided into the following three scenario sub-regions (see also Fig. III.1a):

Higher-Ouémé: This sub-region can be characterized as a rural region with a low population density and only one rainy season.

Middle-Ouémé: This sub-region is also a rural region, and it forms the southern border of transhumance.

Lower-Ouémé: This sub-region, in contrast, is characterized by a well-developed infrastructure and shows a high rate of urbanization that goes hand-in-hand with a high population density. There are two rainy seasons.

The research area in Morocco, from the upper Drâa valley to Lake Iriki, was divided into the following three scenario regions (see also Fig. III.1b):

High Atlas: This sub-region can be characterized as a marginalized mountain region with a poorly developed infrastructure. Water availability is, however, relatively good, and is thus only a weak limiting factor for agricultural production.

Basin of Ouarzazate: Good water availability is a specific feature of this sub-region. It is also characterized by a well-developed infrastructure and strong urban centers in Ouarzazate, Boumalne Dadès, Kalaat M'gouna, Taznakht and Tinghir.

Oases south of the Mansour Eddahbi Dam: Low water availability is a main impediment for economic development is this sub-region. Agriculture is dependent on the management of the Mansour Eddahbi dam.

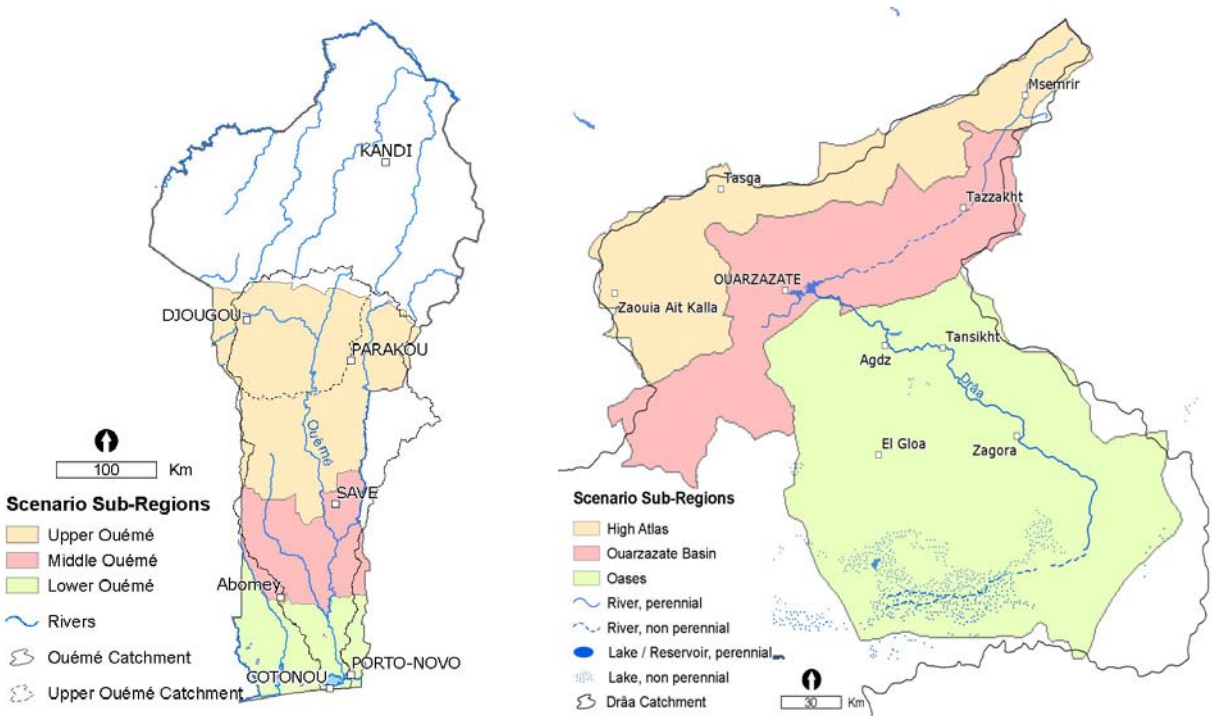

Fig. III.1: Scenario regions: a) Benin b) Morocco.

Intervention scenarios

Intervention scenarios allow the decision maker to depict future consequences of policy interventions. In other words, they describe the future state of society and the environment under the influence of a certain policy or decision. Intervention scenarios are also known as 'mitigation' or 'policy' scenarios. In the schematic below (see Fig. III.2), the principles of intervention scenarios are given: the red curves depict the temporal evolution of the three reference scenarios (including a business-as-usual scenario) for a certain quantity of interest, i.e., a response indicator. An action X at time t_1 or an action Y at time t_2 will significantly change the temporal evolution path (blue lines) of the response indicator until the target year 2025.

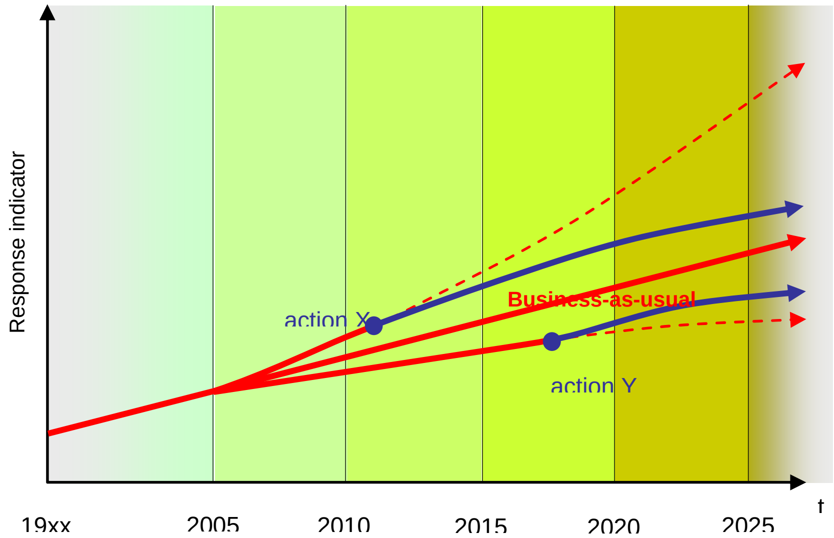

Fig. III.2: Schematic of intervention scenarios.

So far, no decision maker can foresee whether or not his or her intervention will have the desired quantitative effect on the target variable (e.g., the amount of ground water available in an aquifer). There are too many parameters (or response indicators) influencing the target variable, and their interdependencies are too complex to overlook. A computer-based decision support tool as designed in the IMPETUS project (see Chapter II), however, offers the decision maker the option to "play god" as they are guided through the three reference scenarios offered with various options for interventions at different levels. The result of their decision(s) on the target variable will then be graphically depicted and will serve as a scientifically sound basis for the decision maker's 'optimal' policy.

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III.2 Klimaszenarien / *Climate Scenarios*

Introduction

The AR4 (Fourth Assessment Report) of the IPCC (Intergovernmental Panel on Climate Change, IPCC 2007), which is based on an ensemble of global general circulation models (GCMs), projects an overall warming trend for Africa and a substantial drying for sub-tropical North Africa for different emission scenarios until the end of the 21st century. The rainfall projection for tropical West Africa for this century is uncertain. Global climate models used in the IPCC 4AR, for example, differ considerable in the rainfall trend for West Africa using the A1B emission scenario (Christensen et al. 2007, their supplementary figure S.11.13). In order to pursue detailed climate impact analyses from other disciplines (e.g., hydrology, agronomy, health), it is important to recognize that this information is highly insufficient due to its coarse resolution in both space and time. Furthermore, the credibility of these projections has to be questioned due to the physical parameterization of sub-grid processes and the omission of relevant anthropogenic forcing factors (e.g., loss of vegetation and degradation of soils).

Thus, high-resolution regional climate scenarios or, more precisely, 'regional climate change projections' are indispensable for impact studies. According to AR4, these should ideally be based upon information from four potential sources: (1) global climate model simulations; (2) downscaling of simulated data from these global models using techniques to enhance regional details; (3) physical understanding of the processes governing regional responses; and (4) recent historical climate change (Christensen et al., 2007: 849). All suggested pathways have been pursued within IMPETUS the Drâa and the Ouémé catchments and its sub-divisions (see Chapter III.1). As described below, this approach has resulted in a set of regional climate scenarios spanning the so-called phase space of likely and plausible future climatic changes.

Box: Storylines taken from the IPCC Special Report on Emissions Scenarios: Summary for Policymakers (IPCC 2007)

A1: The A1 storyline and scenario family describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. The A1 scenario family develops into three groups that describe alternative directions of technological change in the energy system. The three A1 groups are distinguished by their technological emphasis: fossil intensive (A1FI), non-fossil energy sources (A1T), or a balance across all sources (A1B) (where balanced is defined as not relying too heavily on one particular energy source, on the assumption that similar improvement rates apply to all energy supply and end-use technologies).

B1: The B1 storyline and scenario family describes a convergent world with the same global population, that peaks in mid-century and declines thereafter, as in the A1 storyline, but with rapid change in economic structures toward a service and information economy, with reductions in material intensity and the introduction of clean and resource-efficient technologies. The emphasis is on global solutions to economic, social and environmental sustainability, including improved equity, but without additional climate initiatives.

The hierarchy of dynamical models

In the IMPETUS project, a combination of state-of-the-art dynamical and statistical-dynamical approaches have been applied to meet the above-mentioned IPCC suggestions (1) and (2) with respect to the development of regional climate scenarios. The backbone of the dynamical downscaling technique constitutes a hierarchy of nested dynamical models of the atmosphere as displayed in Fig. III.3. On top of this model chain, one can find the global-scale GCM (general circulation model) ECHAM5 (European Centre Hamburg Model Version 5, Roeckner et al. 2003) coupled with the MPI-OM (Max-Planck-Institute dynamical Ocean Model). This ocean-atmosphere coupled model has a horizontal resolution of about 200 km, and it allows for multicentury integrations. It is forced with increasing greenhouse gas concentrations and sulphate aerosols: as observed historically and according to the IPCC SRES (Special Report on Emission Scenarios) A1B and B1 for the present day until the year 2100. Land use changes are not taken into account. The REMO (Regional Model) regional climate model (Jacob 2001) addresses the synoptic processes at the continental scale: the model has a horizontal resolution of 0.5° (an approximately 55-km grid box spacing) and covers tropical and northern Africa. It has been nested into the GCM, and multi-decadal simulations have been carried out up to the year 2050. Future losses in vegetation and the degradation of soils were considered according to FAO (Food and Agriculture Organization) estimations (Paeth et al. 2009). On the regional scale, the non-hydrostatic LM (Lokalmodell) of the DWD (German Weather Service) has been nested into REMO. The horizontal resolution is between 28 – 7 km and the integration time is up to one year. At the lower end of the model hierarchy on the very local scale, the non-hydrostatic model FOOT3DK (Flow Over Orographically Structured Terrain, 3-dimensional, Köln Version) is used with a horizontal resolution between 7 – 1 km and with a total simulation time on the order of one to three days. For technical aspects of the downscaling techniques and the results obtained, the reader is referred to sections at the end of this chapter.

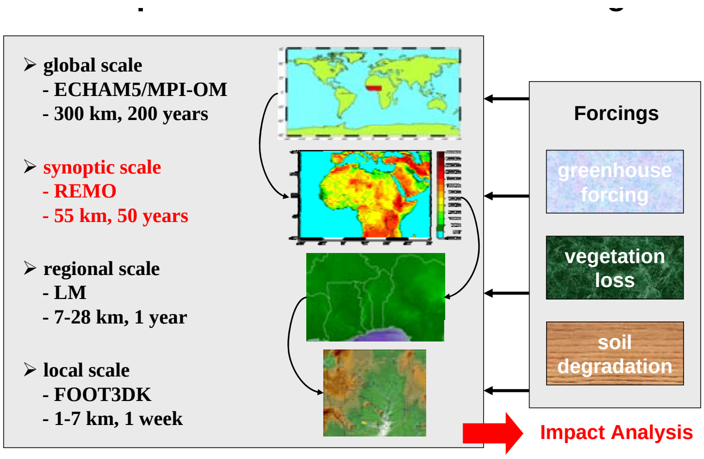

Fig. III.3: The IMPETUS model hierarchy and driving forces

Construction of alternative climate scenarios

It is important to note that research within IMPETUS has revealed that not all regional climate processes are adequately represented in the numerical models. In order to cover the range of plausible pathways of regional climate change, three regional climate scenarios are defined based on:

a) *Climate model projections*
b) *Process understanding*
c) *Persistence of recently observed trends (business as usual)*

To construct the (a) scenario, an ensemble of regional model simulations – driven by global IPCC greenhouse gas emission scenarios A1B and B1 (see box below) and FAO-based land use changes – were performed using the IMPETUS model hierarchy (Fig. III.3) and statistical downscaling techniques. This has resulted in a set of high-resolution (both in space and in time) time series of relevant climate parameters. It has also enabled the simulation of a wide range of impacts involving the application of numerical and expert models of other disciplines such as agriculture, hydrology and health (see, e.g., Chapters IV.1, IV.2, IV.5, and V.1). Note that the SRES scenarios A1B and B1 are an external forcing of the GCMs (and, thus, an indirect forcing of the regional models used) and must not be mixed up with the (a) scenarios generated within the framework of the IMPETUS project. It should be mentioned here that most impact studies within IMPETUS use scenario (a) time series that were generated from REMO output in which REMO was nested in the ECHAM-GCM and forced with either A1B or B1 global emission scenarios. When REMO scenarios with a 0.5° resolution were still too coarse, or point information was needed, further downscaling was carried out by using a weather generator. For clearer signal differences between A1B and B1, forced REMO output for the target year for some impact studies was extended to 2050. Note that mathematical models could not be applied in the (b) and (c) scenarios, and thus the impact studies were rather limited. Nevertheless the (b) and (c) scenarios are very important for judging the quality of the (a) scenarios.

Characteristic tables for Benin and Morocco

As mentioned in Chapter III.1, the IMPETUS catchments are divided into three sub-regions. As a consequence, the *climate model projections* are given for each sub-region separately. The target years are 2025 and 2020 for Benin and Morocco, respectively (see also Chapter III.3). In the following tables (Tab. III.1 and Tab. III.2), characteristic climate changes for each catchment with its sub-regions are given for the three alternative climate scenarios. This is done to help none-climate experts and decision makers get a concise overview of the quintessence of different climate scenarios.

Table III.1: Characteristics of the climate scenarios for Benin

Scenario (a)	Scenario (b)	Scenario (c)
Upper Ouémé		
• strong reduction in annual rainfall • less heavy rain events • delayed monsoon onset • remarkable warming - particularly in summer	• strong reduction in annual rainfall due to stronger wind convergence at the coast and land degradation • substantial warming • stronger climate extremes	• land degradation and warmer surface temperatures in the Indian Ocean, maintaining below-normal precipitation anomalies • warming of 0.35°C per decade
Middle Ouémé		
• slight weakening of the hydrological cycle • slightly enhanced seasonality • strong warming	• moderate weakening of the hydrological cycle due to less evapotranspiration upstream (enhanced land use) • considerable warming • stronger climate extremes	• land degradation and warmer surface temperatures in the Indian Ocean, maintaining below-normal precipitation anomalies • warming of 0.15°C per decade
Lower Ouémé		
• strong reduction in annual rainfall and delayed onset • less heavy rain events • reduced climate seasonality and earlier withdrawal • strong warming	• enhanced precipitation due to an intensified summer monsoon circulation and latent heat fluxes over the Gulf of Guinea • moderate warming	• land degradation and warmer surface temperatures in the Indian Ocean, maintaining below-normal precipitation anomalies • no temperature trend

Table III.2: Characteristics of the climate scenarios for Morocco

Scenario (a)	Scenario (b)	Scenario (c)
High Atlas		
• snow line rise by 200m • reduced precipitation due to decreasing number of lows from the north • reduced seasonality • strong warming in winter	• snow line rise by 200m, • more intense but less frequent precipitation events • no trend in annual precipitation • more extreme precipitation events	• snow line rise by 200m • ongoing tendency toward reduced precipitation in winter • still large interannual variability
Basin of Ouarzazate		
• substantially reduced precipitation and seasonality • more intense but less frequent precipitation events from tropical-extratropical interactions • strong warming in winter	• slightly increased precipitation due to enhanced moisture transport for: a) tropical-extratropical interaction b) pressure minima off the Moroccan coast	• no change in the long-term mean precipitation amount • still a tendency toward dry or wet periods over several years (decadal variability)
Southern oases		
• slightly reduced precipitation • more intense but less frequent precipitation events from tropical-extratropical interaction • reduced seasonality • weak warming in winter	• slightly increased precipitation amounts due to enhanced moisture transport for: a) tropical-extratropical interaction b) pressure minima off the Moroccan coast	• no change in the long-term mean precipitation amount • still a tendency toward dry or wet periods over several years (decadal variability)

Dynamical downscaling, model bias correction and the Weather Generator (WEGE): an example for Benin

For the simulations with REMO, land-cover changes are converted into model grid box parameters, like vegetation and forest fraction, albedo, leaf-area index and roughness length at the model's scale (Paeth et al. 2009). The combined GHG (greenhouse gas) and LUCC (land use and land cover change) scenario is supposed to be more realistic than the classical IPCC scenario approach with radiative forcing alone (IPCC 2007). This is because the effect of land degradation is evident from observational data and can be assumed for the future as well (Zeng et al. 2002; Feddema et al. 2005).

The process of increasing land-use and deforestation in Africa is difficult to anticipate because it takes place at the local scale and is subject to random processes in space and time. Nonetheless, the large-scale process of land degradation is mainly dependent on demographic growth, which can be projected with quite high confidence. Based on FAO and UN (United Nations) estimates on regional population growth in Africa, a stochastic model has been developed that produces a random pattern of high-resolution land-use changes at the 1 km by 1 km scale of the USGS land cover classification data set (Hagemann 2002). In addition, some reasonable constraints have been taken into account. These include, for instance, accelerated land degradation along traffic axes, around urbanized areas and in the desertification belt in the Sahel Zone. The result is a transient pattern of land-use changes (LUCC) that reflects the spatial heterogeneity of the real process and is consistent with the FAO and UN estimates at the regional-mean level. Between 2000 and 2025 the expected demographic growth leads to a general transformation from forests and woody savannas to croplands and savannas in West Africa. In addition, the urbanization proceeds, especially along the Guinea Coast. For details of the LUCC assessment until 2050, the reader is referred to Paeth et al. (2009).

Post-processing of climate model data

All climate models are subject to systematic errors. These arise from limited resolution, uncertain physical parameterizations, neglected feedbacks and unknown processes (Xu 1999). Precipitation, especially, is the end product of a causal chain of nonlinear processes like radiation, convection and cloud microphysics. These are usually parameterized and, hence, characterized by nonlinear error growth. While systematic errors may be less troublesome for the analysis of climate trends, they are strictly problematic when climate model data are used as quantitative inputs for impact studies. This is particularly true for hydrological applications (Lebel et al. 2000). Hydrological models mostly require rainfall information at a very high spatio-temporal resolution. In the IMPETUS project, this information is taken from simulations with the REMO regional climate model (Jacob 2001). While REMO is able to reproduce most of the basic features of the observed African climate (Paeth et al. 2005), simulated precipitation is systematically underestimated over sub-Sahelian West Africa (Fig. III.4). In addition, the 0.5° resolution of REMO is inconsistent with the local rainfall information required by hydrological and other impact models used in IMPETUS.

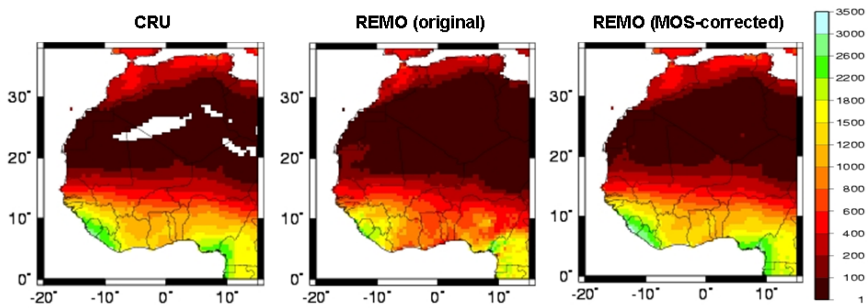

Fig. III.4: Long-term mean pattern of observed annual precipitation in West Africa from observations (CRU; New et al., 2000), original REMO output and REMO output corrected by MOS

Because of these limitations, a two-step post-processing of the simulated precipitation data from REMO has been undertaken prior to using the data for impact studies in IMPETUS:

(1) The systematic errors in the monthly rainfall totals and the seasonal cycle have been adjusted to observed values from the CRU (Climate Research Unit) data set (New et al. 2000) by carrying out MOS (model output statistics; Hansen and Emanuel 2003). In the present case, the MOS consists of a multiple linear regression model with a stepwise extension of predictors and a cross validation approach, which are used to identify robust predictors. In addition to simulated precipitation, the predictors are simulated sea-level pressure, wind, geopotential height and tempera-

ture. These kinematic and thermodynamic variables are assumed to be linked to observed precipitation and to be more reliable from climate models than from simulated rainfall. The MOS-corrected precipitation climatology is presented in Fig. III.4. In the figure, it is evident that the corrected model precipitation is now in good agreement with the observed pattern.

(2) The MOS correction still leads to regional-mean precipitation on the basis of the 0.5° by 0.5° model grid boxes. At the daily scale, this regional-mean presentation differs strongly from the real spatial distribution of the rain events. This is particularly true in tropical Africa, where mesoscale convective systems and squall lines are associated with a very heterogeneous pattern of locally confined rain events (Fink and Reiner, 2003, Fink et al 2006). In order to transform the MOS-corrected regional-mean precipitation from REMO to a local pattern of rain events, a WEGE (weather generator) has been developed in the IMPETUS project. This weather generator is centered over Benin according to the focus of the hydrological models. The WEGE produces virtual station data, matching the BDMET (base de données météorologiques) stations in Benin (Le Barbé et al. 2002), and is composed of three components (Fig. III.5): (i) The dynamical part is taken from the MOS-corrected REMO precipitation. This part represents the synoptic-scale atmospheric processes and the climate change signals. (ii) The relationship between topography, atmospheric flow and windward-lee effects on local rainfall is used as a physical downscaling component. (iii) A large part of the spatial distribution of rain events is random. This stochastic component is derived from observed station data in Benin and is found to account for more than 90% of the subgrid-scale rainfall distribution. The resulting 'virtual' station data set is finally adjusted to the statistical characteristics of the observed daily precipitation at the BDMET stations by so-called probability matching (Helmer and Ruefenacht 2005). This is a procedure that transforms a data set with a simulated distribution function to a new data set that matches the observed distribution function. The final data set maintains the larger-scale climate signals from REMO, and it agrees with the typical spatial and temporal distribution of the observed rain events in Benin.

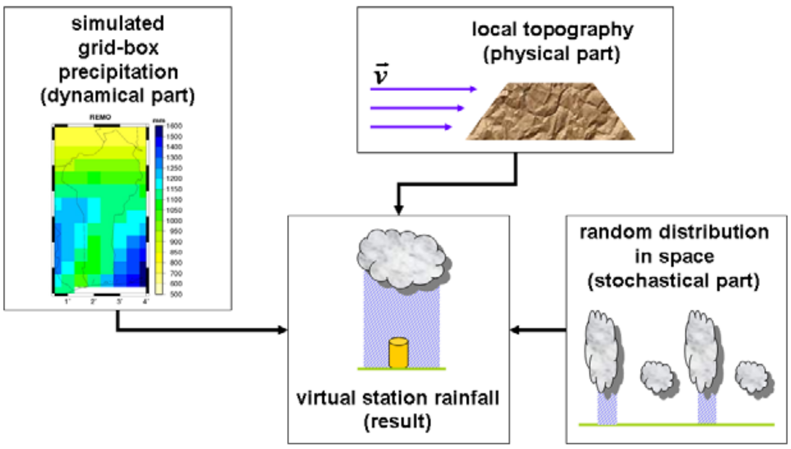

Fig. III.5: Scheme of the weather generator with dynamical, physical and stochastic components leading to virtual station data with local rainfall information

Fig. III.6 depicts the efficiency of the WEGE. Compared with the observations, the time series of simulated daily precipitation from the original REMO output reveals an incorrect seasonal cycle that underestimates heavy rain events and misses dry spells during the rainy season. The time series produced by the WEGE is in good agreement with the observations. Note that the WEGE is not meant to reproduce the observed sequence of daily rain events, but their statistics. This is demonstrated in Fig. III.7. Here, the Gamma distribution of the observed daily rainfall is inconsistent with the original model output, which tends to underestimate the extreme events while weak rainfall events occur too frequently. In contrast, daily precipitation from the WEGE corresponds to virtually the same Gamma distribution as the observations. The post-processed precipitation data from REMO proved to be sufficiently reliable for various impact studies in the IMPETUS project, including hydrological modeling and the crop and malaria models.

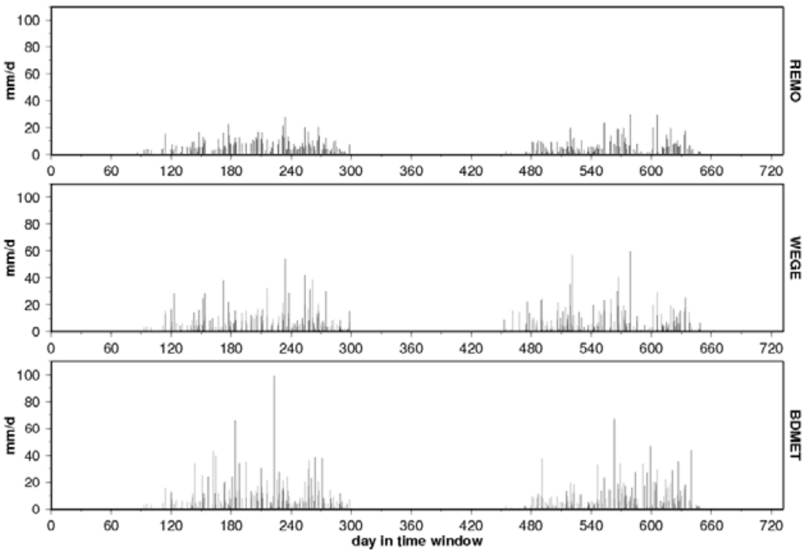

Fig. III.6: (top panel) Time series of daily rain events at Abomey-Calavi station during two exemplary years from original REMO output, virtual station data from the WEGE (middle panel), and observations (lower panel).

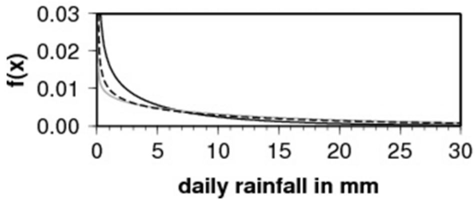

Fig. III.7: Gamma distributions of daily rain events at Abomey-Calavi station from original REMO output (black solid line), virtual station data from weather generator (grey solid line), and observations (black dashed line).

The simulated changes in annual-mean near-surface temperature according to the A1B scenario and the IMPETUS LUCC assessments until 2050 (see Paeth et al. 2009) are shown Fig. III.8a. The highest amplitude with up to 4.5°C warming until 2050 occurs in sub-Sahelian Africa, exactly where the prescribed LUCC peaks. The greenhouse gas forcing without LUCC leads to a slightly different picture with more homogeneous warming rates over the land masses (not shown). From the comparison of the A1B scenario with and without LUCC it can be derived that the LUCC contributes around 1°C – equivalent to one third – to the overall heating. Of course, this effect is confined to sub-Sahelian Africa where the LUC mainly takes place. In all regions and scenarios the temperature trends are statistically significant and are consistent with different ensemble members. The trend patterns of annual precipitation are much more heterogeneous in space (Fig. III.8b). The combined radiative and LUCC forcing lead to a remarkable drying on the order of 25 to 40% of the present-day totals. In contrast, the greenhouse gas forcing alone comes along with a completely different trend pattern with mostly incoherent and insignificant changes. This implies that the weakening of the hydrological cycle over sub-Saharan Africa is mainly linked to land degradation rather than radiative heating.

In summary, the consideration of the continental-scale changes in land use and land cover until 2050 in the regional model REMO caused a significant drying trend that is already discernible about the middle of this century. Moreover, the significant greenhouse gas induced temperature trend pattern was changed in a reasonable manner when compared to the IPCC 4AR A1B scenarios; the strongest warming occurs in the savanna belt of West Africa rather than in the western Sahara. These novel findings were utilized in several climate change impact assessments for West Africa (e.g. Chapters IV.1, IV.2, and IV.5).

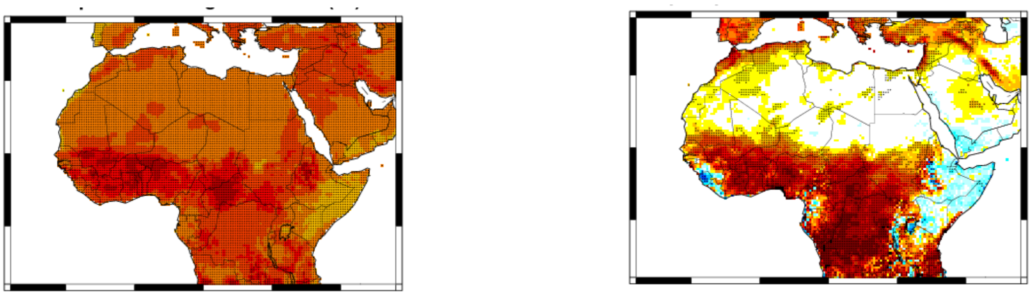

Fig. III.8: Simulated linear changes in ensemble-mean annual temperature in °C (a) and precipitation in mm (b) for the combined A1B and LUCC scenario (for details see text) based on three REMO ensemble realizations. Statistically significant trends at the 5% level are dotted.

The statistical downscaling approach used in the High Atlas region

Because particularly hydrological applications request time series of daily values of meteorological parameters, a purely statistical downscaling of climate scenarios has also been undertaken for the Drâa region. The objective was to create time series of rainfall, temperatures, moisture, radiation, and wind for the near-surface layer (2m height) with daily resolution from REMO climate model data. Statistical properties of climate model data usually differ considerably from point observations, because model variables are always calculated as representative averages for model grid boxes. As a consequence in case of rainfall, the model tends to more frequent, but smaller rainfall rates.

From this consideration it is clear that for the atmospheric forcing of hydrological models, results of regional climate models have to be transformed in a way that their statistical characteristics are more similar to these of observed data. The most important parameters to be transformed are rainfall rates and temperatures. An additional issue for the practical application of climatic data is the reduction of the amount of data. For this purpose, the Drâa region was divided into a small number of zones of either similar climatic characteristics or as sub-catchments of the Drâa and its tributary rivers.

The simply achievable, but most important predictors for small-scale variability are topographic characteristics like surface elevation and land use data. In the statistical downscaling approach used here, they have been aggregated on a 1 km grid. The procedure consists of two steps: the estimation of a transfer matrix based on multiple regression methods and the correction of statistical properties of rainfall.

In the first step, regression coefficients of sufficient predictors with observed climate parameters from observing stations are calculated in a multiple regression. The observational data set used consists of four climatic stations located between Ouarzazate and the High Atlas Mountains (Ouarzazate, Agouim, Ifre and Ait Mouted), and the IMPETUS climate stations. Predictors are climate model data and topographic characteristics. In the Drâa valley, surface elevation, exposition and location in space are the most important candidates for topographic predictors, because local climate conditions are steered by three factors: (i) the NW-SE gradient of rainfall, (ii) surface elevation and (iii) slope of the surface, because, for example, a northerly slope will be slightly cooler and wetter than a southerly slope. The resulting transfer matrix is applied on a combined set of predictors consisting of climate model data and the above-mentioned topographic data. For temperature, wind and relative humidity, this first step is applied on daily data. Due to the high day-to-day variability, for rainfall the first step is applied only for annual and monthly data.

In the second step, statistical properties of rainfall data from observations are transferred to the climate model data. This is simply achieved by estimating the height dependent seasonal march of rainfall probability from observations and recalculating the number of rainfall days in model data under the constraint of preservation of monthly rainfall sums. This results in less frequent, but stronger rainfall rates, as presented in Fig. III.9.

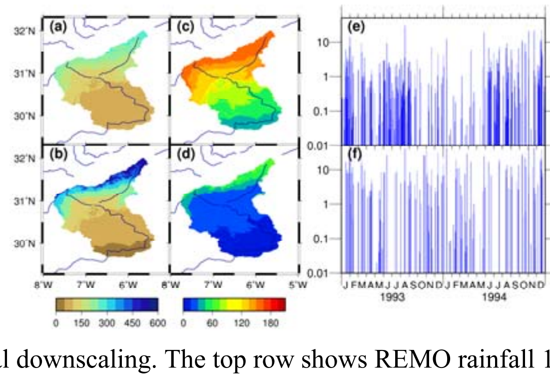

Fig. III.9: Results of statistical downscaling. The top row shows REMO rainfall 1960-2000 using multiple regression coefficients obtained from climate model data and topography: (a) mean annual rainfall sums in mm, (c) average number of rainy days per year, (e) exemplary time series of daily rainfall for the high mountain zone in mm/day. The bottom row, images (b), (d) and (f) shows the same for rainfall interpolated using regression coefficients from climate station observations.

The assessed changes in climate scenarios for the period 2011-2050 are shown in Fig. III.10. The maps reveal that the rainfall is reduced between 5% (mountain area) and 30% in the southern regions for the SRES A1B scenario and by 5% and 20% for the B1 scenario. The atmospheric warming, represented by the 2m-temperature accounts for 1.2°C in the SRES A1B and 1°C in the B1 scenario, for both scenarios is slightly stronger in the mountain region.

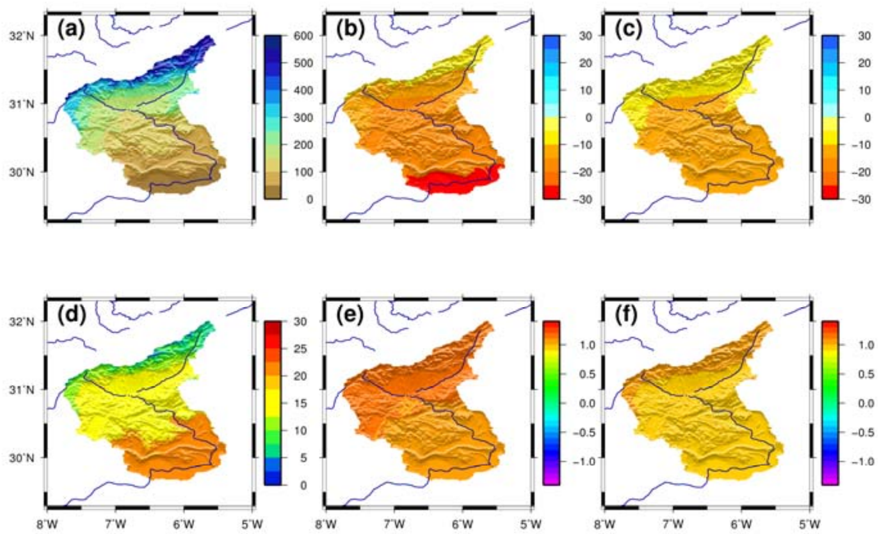

Fig. III.10: Regional downscaling of climate scenarios. Top row: Annual mean rainfall for (a) present day climate (1960-2000, in mm), (b) difference scenario SRES A1B (2011-2050) minus present day (in percent of the present day climate value) and (c) scenario B1 (2011-2050) minus present day climate in percent. Bottom row: (d) annual mean 2m-temperature in °C, (e) differences between SRES A1B minus present day in °C and (f) differences between SRES B1 minus present day.

Some additional results pertinent to the impact studies described in Chapter V are the decrease in the return periods of extreme dry hydrological years (September-August) whereas the return periods of wet years remain unchanged until the middle of the 21st century (Born et al. 2008b). In spite of the drying trend suggested by REMO, the statistical downscaling of daily rainfall from this model hints at an increase in extreme daily rainfall in the High Atlas Mountains. In contrast, days with extreme rainfall may occur less often at the Saharan foothills of the Atlas Mountains.

The statistico-dynamical downscaling approach using circulation weather types: an example for the High Atlas region

In the Atlas Mountain chains, long-term station records of meteorological variables are rare, and the station density is very low. As a consequence of the orography and the sparse station data, gridded products like the CRU temperature and rainfall data sets have an exceptionally low quality in the northwest African mountain chains. Thus, the application of model error correction and weather generator techniques, which both require the use of observational data, is limited. An alternative approach is statistico-dynamical downscaling, comprising a recombination of meteorological parameters stemming from a fixed number of different model episode simulations (e.g., Fuentes and Heimann 2000). These episodes cover a set of distinct circulation weather types that have been identified for the region from large-scale flow patterns. For example, episodes of westerly flow have been simulated using a high-resolution (i.e., 3 km) meteorological model to obtain a physical-based distribution of precipitation in the Drâa catchment area. In the following sections, this regionalization method is outlined, and its advantages and limitations are discussed.

Identification of Circulation Weather Types (CWTs)

The statistico-dynamical downscaling method in this case utilizes the physical relationship between the mean sea-level pressure fields on the synoptic scale (i.e., on spatial scales of several hundreds to thousands of kilometers) and precipitation on the mesoscale (i.e., on spatial scales of several kilometers). The mean sea-level pressure fields are used to identify so-called CWTs (Circulation Weather Types, for further reading: Jones et al. 1993). CWTs categorize pressure fields into eight wind direction types and two circulation types (cyclonic and anti-cyclonic). The frequency of occurrence of the CWTs is shown in Fig. III.11.

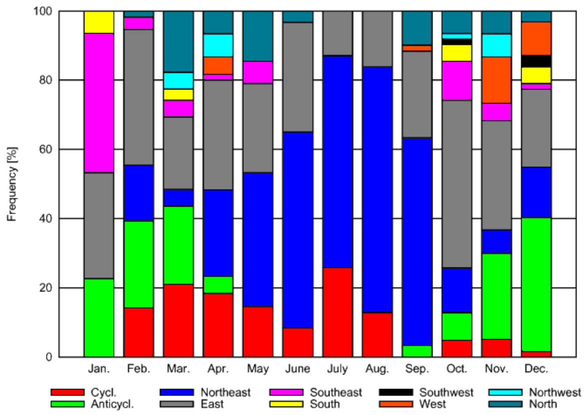

Fig. III.11: CWT distribution for 2002 by month.

Overall, the most frequent CWTs in 2002 is "northeast," indicating that low-level winds from a northeasterly direction are prevalent. The CWT northeast occurs mostly during the summer, but is rare in winter. Taking into account that in the area of the Drâa catchment precipitation (not shown here) peaks in the transitional seasons (see Born et al. 2008a), it is to be expected that the CWT northeast is not responsible for most of the precipitation throughout the year. The CWTs mainly responsible for the precipitation are the cyclonic and southerly flows. The latter can transport moisture into the region from the tropical and subtropical Atlantic Ocean (Knippertz 2003a, 2003b). Neither occur as frequently as the CWT northeast.

The frequency of the CWTs, combined with information about precipitation behavior within the different CWTs, is used for the statistical part of the downscaling procedure. For the dynamical part, representative dates for the different CWTs are chosen, and the output of the LM at a spatial resolution of 7 km x 7 km is used to force the FOOT3DK model. The LM was forced by observation at its lateral boundaries. Since the LM run is available for only fourteen months, the different CWTs are grouped into six classes to obtain a larger number of representatives: cyclonic, anti-cyclonic, northeast and east, southeast and south, southwest and west, northwest and north. Representatives with and without precipitation for each CWT group are then simulated with FOOT3DK. A further constraint was the limited computer capacity. Therefore, the 24-hour simulations were run for 23 representatives at a resolution of approximately 3 km x 3 km for the region, as shown in Fig. III.12. These 23 episodes occurred between November 2001 and December 2002. This is the physical part of the downscaling.

FOOT3DK output is recombined with the information of the CWT frequency to spatially highly resolved distributions of precipitation or evaporation. The recombination itself operates with an accumulation of the precipitation or evapotranspiration of the representatives per grid-point and given period (for further reading: Huebener and Kerschgens 2007).

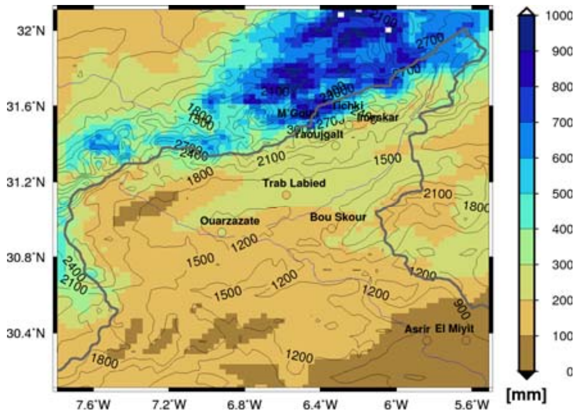

Fig. III.12: Recombined distributions of precipitation for 2002. The gray line is the border of the Drâa catchment; black lines are the orographic heights in m. The colored dots indicate measured precipitation at IMPETUS stations.

For 2002, the results are shown for recombined precipitation in Fig. III.12. The precipitation displays the expected north-south distribution with higher values on the northern flank of the High Atlas Mountains and drier conditions south of the main divide. The recombined accumulated precipitation sum and the measurements taken at the IMPETUS stations are in good agreement (Fig. III.12, colored dots). Bearing in mind that this is a comparison of a point measurement and the mean precipitation of a 9-km² grid, we cannot expect a perfect fit. By inspection of Fig. III.12, it can also be concluded that the method is capable of reflecting the orographically modulated annual precipitation in 2002, especially the role of the Atlas mountain crest as a weather divide.

Assuming that the physical relation between the large-scale flow and the local meteorological variables is not affected by the climate change, any change in the latter can be assessed by statistically significant changes in the CWT distribution in climate model simulations. The future changes in CWT distribution have been assessed based on REMO mean sea-level pressure data for the SRES scenarios A1B and B1 for the period 2036-2050. The reference period is 1986-2000.

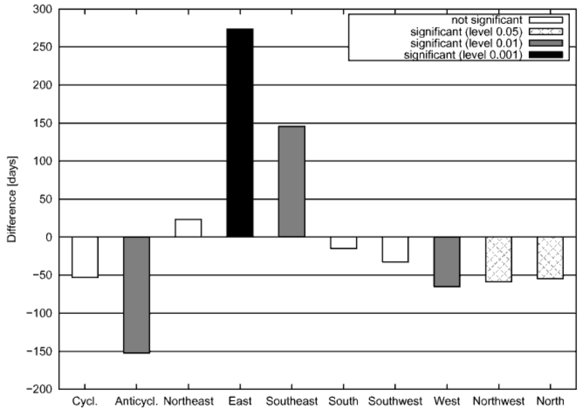

Fig. III.13: Difference in days of the occurrence of the CWTs in all three REMO ensemble members of the A1B scenario (2020-2049) and the control period (1970–1999). The statistical significance given in the upper-right box is based on a two-sided χ2 cross tabulation test.

In Fig. III.13, the significant changes in the CWT distribution for A1B are shown. The most remarkable feature in figure II-3.2.11 is the statistically highly significant increase in CWT east and CWT southeast. This is consistent with a northeastward shift of the Azores High found in ECHAM5 and in many other IPCC AR4 global models. As a consequence of the change in frequency of occurrence of the CWTs in the A1B scenario, the recombined precipitation shows a statistically significant increase in annual precipitation for the period 2020-2049 in the Djebel Saghro Mountains and large parts of the Ouarzazate Basin (Fig. III.14). Due to a decrease in westerly flow and cyclonic weather types, rainfall decreases north of the High Atlas Mountain chain and in the Anti-Atlas Mountains, including the Djebel Siroua massif.

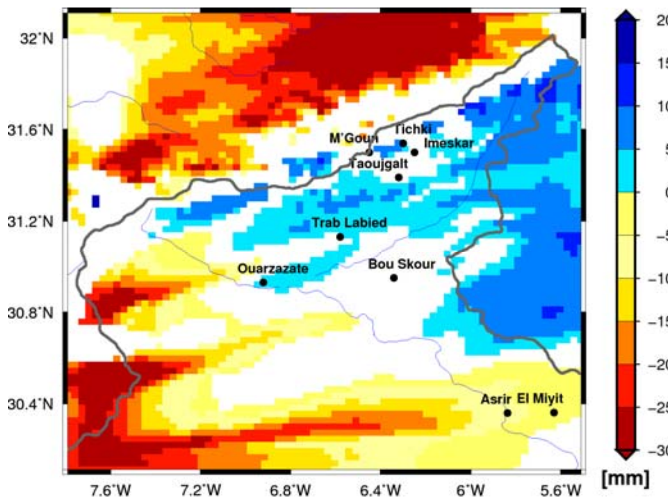

Fig. III.14: Difference in annual precipitation in all three REMO ensemble members of the A1B scenario (2020–2049) and the control period (1970–1999). Only statistically significant changes based on a two-sided student-t test are plotted in color.

Summary of the model-based methods of regionalization of climate information for climate scenarios

All state-of-the-art regionalization methods utilized in IMPETUS, such as dynamical downscaling, statistico-dynamical, and statistical approaches, have been used for the model-based generation of regional scenarios.

For Benin, where a relatively good coverage of station data was available over many decades, we conclude that the application of the bias-corrected regional model, as well as the use of weather generators, is the most suitable approach. Regional models, in general, have difficulty simulating the spatio-temporal distribution of rainfall. However, it can be assumed that they provide a reasonable climate change signal in the larger-scale (thermo-) dynamic fields (e.g., wind and temperature). The bias-correction and the weather generator use the observed statistical distribution and their moments to (a) correct model bias in precipitation and (b) to downscale the climate change signal in precipitation to a single station. Moreover, the IMPETUS regional modeling results suggest the consideration of the projections of continental land-use changes and vegetation degradation in the regional model scenario runs.

In Morocco, the paucity of station data and the relatively low quality of gridded products (e.g., CRU data) suggest that the bias-correction and weather generator approach shall be complemented by alternative downscaling methods. In the mountainous region of the High Atlas, the statistico-dynamical approach using circulation weather types is a promising alternative approach. This method, for example, suggests a somewhat wetter climate for the coming decades south of the High Atlas Moduntains – a trend that is contrary to the IPCC global model and the REMO projections. However, such a scenario was deemed to be plausible due to the strong contribution of tropical-extratropical interactions to the annual rainfall on the Saharan flank of the Atlas Mountains. This method has its own uncertainties. The most noteworthy are likely the selection and number of the representatives and the assumption that the mean local rainfall distribution within a given CWT does not change from to the present climate to the future climate.

If project resources permit, the IMPETUS experience suggests using a variety of regionalization methods to assess plausible and physically consistent pathways of future climates. It is desirable, in any case, to use climate projections from an ensemble of several models. The use of different greenhouse-gas emission scenarios is obsolete if projections are made for the next two to three decades. Finally, we anticipate that the variety of regionalization approaches applied in IMPETUS will remain state-of-the-art techniques for a number of years. The reasons for this lie in the sustained deficiencies in model physics and computer power limitations that both cause substantial biases in global and regional models.

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III.3 Sozioökonomische Szenarien / *Socio-economic Scenarios*

Introduction

Scenarios help to describe potential future problems and to consider alternatives in the context of uncertainties. Furthermore, they might help to improve our common understanding of problems, to detect and to test our assumptions and to identify useful problem-solving approaches. Scenarios enable us to combine the analysis of long-term development of the natural environment (in this case, water) with the analysis of long-term impacts of political programs and measures. At the same time, scenarios help us to better understand the mutual relationships between the national, regional and local levels.

Scenario analysis have become a common state-of-the-art tool in support of environmental decision-making (e.g., Marsh 1998; Ringland 1998; Shackley and Deanwood 2003; Leney et al. 2004; Carpenter et al. 2006; UNEP 2005; Alcamo 2008; Mahmoud et al. 2009). Scenario analysis with either independent development of socio-economic and climate scenarios or ‘co-evolutionary’ (Lorenzoni et al. 2000) scenario techniques are widely used in interdisciplinary water resources research projects (e.g., Gaiser et al. 2003; Shackley and Deanwood 2003; Means et al. 2005; Carpenter et al. 2005; Alcamo 2008; Lui et al. 2008).

In the framework of the IMPETUS project, three socio-economic scenarios were developed for both Morocco and Benin in addition to the three climate scenarios (see Chapter III.2). Being formally independent both scenario sets permit a clearer distinction between the effect of physical climate change and socio-economic change (e.g., Shackley and Deanwood 2003). Unlike to Mahmoud et al. (2009), which restrict socio-economic scenarios to ‘demographic driving forces and the sensitivity, adaptability and vulnerability of socio-economic conditions’, the IMPETUS socio-economic scenarios encompass future environmental factors and conditions, and technological changes affecting societal and environmental growth besides economic, political, and societal factors. The time range for the two catchments, up to 2020 for Morocco and up to 2025 for Benin, differ due pre-existing long-term strategy papers of the respective governments (Bénin 2025: ALAFIA, Stratégies de développement du Bénin à long terme, Minist. de Coord. Plan. Devel. Empl., (PNUD 2000); Stratégie 2020 de développement rural, Document de Réference (Conseil Général du Développement Agricole au Maroc 1999). The temporal resolution is five years. As described in Chapter III.1, each river catchment was spatially divided into three homogenous scenario sub-regions according to its demographic, economic, and natural framework (see Fig. III.1).

As the analysis of future water availability requires a sound understanding of the current processes of the various aspects of the hydrological cycle, all disciplines contributed significantly to the scenario development with the necessary input. Involvement of stakeholders from the beginning of the process helped to create convincing descriptions of alternative futures and prevented scientists from incomplete or even incorrect valuation of certain driving forces or response indicators. Furthermore, stakeholder participation throughout the process might assure the subsequent use of the socio-economic scenarios. The structure of the scenario development process is given in Fig. III.15.

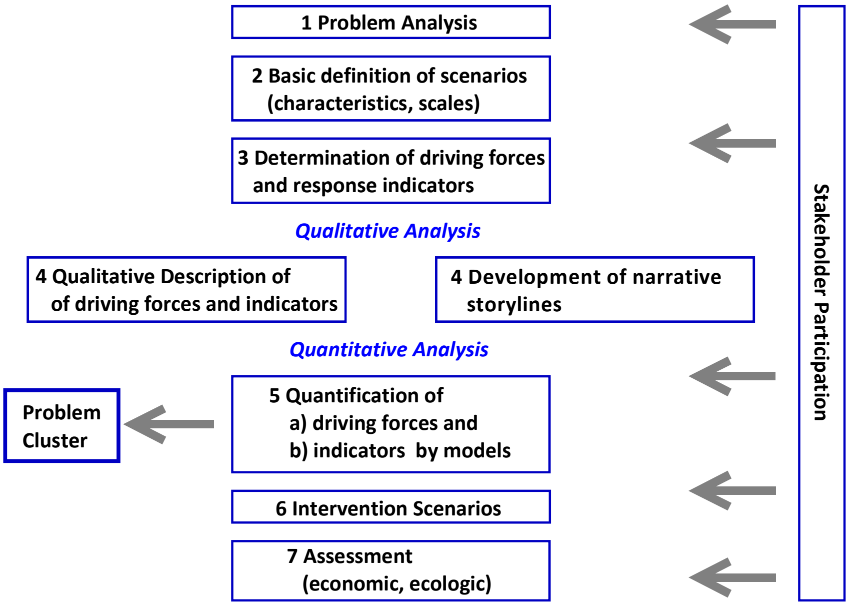

Fig. III.15: Overview of the scenario development process in the IMPETUS project.

Scenario development started with the definition of the main characteristics and spatial scales of the scenarios (see Fig. III.1). Furthermore, the main drivers and their respective response indicators were selected and qualitatively described in a so-called 'qualitative trend-matrix'. As economic, social and environmental developments influence the availability of fresh water, a 'qualitative trend-matrix' covers all key aspects, with around 80 variables for each country. Based on this broad data set, with contributions from all disciplines and the input of the stakeholders, the narrative storylines of the socio-economic IMPETUS scenarios were woven by a smaller group of scientists.

Quantification of both climate and socio-economic scenarios was performed in the context of the various problem clusters with a set of suitable models, either numerical or expert. Almost every discipline adapted existing models to the targeted regions. In order to solve the multidisciplinary questions of the problem clusters, the disciplinary models were often loosely coupled in several spatial decision support systems (SDSS) (see Chapter II). A full coupling of two numerical models as given within the SDSS PEDRO was one of the few exceptions (see Chapter II.8). Hence the qualitative storylines give the descriptive guidance on the quantification; each researcher had to define the socio-economic key factors for his simulation models (e.g., Jakeman et al. 2006; Ngugen et al. 2007; Scholten et al. 2007). Assessment of the scenarios was performed by either qualitative or quantitative response indicators.

With the two last steps of the scenario analysis (see Fig. III.15), the three socio-economic scenarios of each country were refined by simulating various measures in the intervention scenarios to compare their effects on water availability in the future projections. Measures vary between political decisions, such as changes in fertilizer policy (see Chapter IV.1: tax exemption of fertilizer in Benin), and technological modification of agricultural practices (see Chapter IV.2: drip versus traditional flood irrigation in Morocco).

IMPETUS socio-economic scenarios for Morocco

In order to investigate the effects of global and regional change on the societal, economic and environmental conditions and thus their influence on the water resources for the Drâa catchment in Morocco, the following three scenarios were developed:

M1: Marginalization– non-support of the Drâa region

M2: Rural development through regional funds

M3: Business as usual.

Table III.3: Characteristics of the socio-economic scenarios for the Drâa catchment, Morocco.

scenario M1: Marginalisation – non-support of the Drâa-Region	**scenario M2: Rural development in the Drâa-Region through regional funds**	**scenario M3: Business as usual**
	Main economic framework conditions	
• Region does not profit from economic upswing • Industry remains marginal • Stagnation of tourism	• Programs for„self-aid • Increase of tourism	• Low rates of industrialisation • Slow increase of tourism, mainly individual
	Agriculture sector	
• Missing innovations • Agriculture areas and livestock farming remains constant • Stagnation of productivity	• Increasing rate of innovations and productivity • Cash-Crops for regional markets • Reduction of livestock farming	• Low rate of innovations • Agriculture areas and livestock farming remains constant
	Political framework conditions	
• Funding programs decreases • Traditional mechanisms of decision-making gain importance at local level	• Intensification of support programs (according to strategy 2020) • Valorisation of local governance	• Funding programs for tourism only • Dualism of modern and traditional forms of administration
	Demographic framework conditions / living quality	
• Increased migration • Demographic polarisation • Deterioration of living conditions	• Decline of migration • Improvement of living conditions	• High rates of migration • Slight improvement in basic needs supply • Education opportunities improve
	Environment and resources	
• Privatisation of water supply (increasing water prices) • Increase of energy costs • Uncontrolled exploitation of resources	• Infrastructure is further extended • Use of renewable energies • Increase of water use	• Increase of energy costs • Water scarcity limits expansion of agriculture areas

The scenario M1 describes a scenario of stagnation and marginalization in the industrial, agricultural, and tourist sectors due to withdrawal of the support of governmental and international institutions. As a result, the marginalization of the region and the impoverishment of the local population accelerate and work migration increases. M2 gives the opposite picture, where the Drâa catchment profits from national funding, which leads to increased productivity in the agricultural sector, strong growth of tourism, and a decrease of migration due to alternative income possibilities. Furthermore, more sustainable use of natural resources, including water and pastures, is possible. Projection of the current trend into the future with scenario M3 shows that industrialization persists at a low level and tourism is restricted to individual tourism in selected areas. Agriculture continues to dominate the economy, but its further expansion is constrained by water scarcity and low-level techniques. Population growth is high in a few urbanized areas despite high rates of work migration and childhood mortality.

The general characteristics of the three scenarios are given in Tab. III.3. The variability between the sub-regions of the Drâa catchment is briefly discusses in narrative storylines. As described in Chapter III.1 (see Fig: III.1) the three regions considered are: the High Atlas, a marginalized mountain region with poorly developed infrastructure, but good water availability, the Basin of Ouarzazate with a well developed infrastructure and good water availability, and the Oases south of the El Mansour Eddahbi dam with low water availability, and an agriculture dependant on the management of the dam).

IMPETUS scenarios for the Ouémé catchment, Benin

The three socio-economic scenarios for the Ouémé catchment in Benin (see Tab. III.4) can be briefly described as follows:

B1 'Economic growth and consolidation of decentralization'

B2 'Economic stagnation and institutional insecurity'

B3 'Business as usual'

With B1, a scenario is developed, which describes a future of political stability and economic growth. Living conditions of the population improve, and the overall pressure of resource depletion decreases due to technical innovations. B2 sketches the opposite path. The influence of a continuing and mutually reinforcing downward spiral of political destabilization and economic depression leads to negative overall economic development, which also undermines the political stability of the country. Living conditions worsen or stagnate at a low level. Resource depletion and resulting conflicts increase. In B3, the current trends persist. The country is successful in maintaining its political stability, but economic development and social welfare do not improve in general. Population growth continues to decline, and the traditional power structures on the local level remain rather unchanged. The overall characteristics of the three scenarios are presented in Tab. III.4.

Comparable to the Drâa catchment, the variability within the spatially differentiated scenario sub-regions (Upper Ouémé: rural, low population density, one annual rainy season; Middle Ouémé: rural, southern border of transhumance; Lower Ouémé: high rate of urbanization, high population density, well-developed infrastructure, two annual rainy seasons) is described in the following storylines.

Table III.4: Characteristics of the socio-economic scenarios for the Ouémé catchment, Benin.

scenario B1: **Economic growth and consolidation of decentralisation**	**scenario B2:** **Economic stagnation and institutional insecurity**	**scenario B3:** **Business as usual**
Main economic framework conditions		
• Constant growth • Deepening of international competitiveness • Growing importance of industrial sectors • Consolidation of the role as a transit country	• Economic stagnation • Decoupling of global markets • Loss of international competitiveness • Declining incomes • Loss of the role as an important transit country	• Strong informal and weak formal economic integration • Low competitiveness on world markets
Agriculture sector		
• Increasing rate of innovations • Expansion of agriculture areas • Increase in processing of agricultural products • Increases in exports	• Missing innovations • Stagnation of productivity • Increase of subsistence farming	• Low rate of innovations • Expansion of agriculture areas and livestock farming
Political framework conditions		
• Political stability • Functional decentralized administrative structures • Development cooperation continues • Foreign investments increase	• Political destabilization • Dysfunctional decentralized administrative structures • Increasing societal conflicts • Decline of development cooperation	• Established societal power structures prevail • Small improvements • Development cooperation continues, but with main focus on poverty reduction
Demographic framework conditions / Living quality		
• Accelerated decline of population growth • Growth of regional cities • Improvement of living conditions • Rise in overall level of education	• Slow decline of population growth • Deterioration of living conditions	• Continued decline of population growth • Growth of regional cities • •Migration into foreign countries • Slight improvement in basic needs supply
Environment and resources		
• Management strategies are implemented • Resource conflicts decline • Water use increases	• Uncontrolled exploitation and use of resources • Resource conflicts prevail • Weak resource management	• Resource conflicts due to shortages • Continued resource management

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Population Projections for Benin

Population growth is seen as one of the most important driving factors for environmental change, especially regarding the loss of biodiversity, resource depletion or degradation and the resulting shortages and scarcities (Harrison and Pearce 2000; UN DESA 2001). Population might affect the environment through increasing pressure on marginal lands, over-exploitation of soils, overgrazing or overcutting of wood resulting in soil erosion, silting and flooding. While this looks like an unilinear causality, the relation between population dynamics and environmental change is often far more complex and linked in many ways and through multiple social and economic mechanisms at various spatial scales. The idea that a causal connection between population growth and environmental degradation is questionable is also indicated in conflicting theoretical approaches that take into account, for example, the role of technological change in enabling adaptations and therefore in accommodating more population or political ecology approaches that see both environmental degradation and rapid population growth as consequences of poverty (Blaikie and Brookfield 1987; Jolly 1994; Blaikie 2008; Simon 2008). However, it is obvious that population dynamics remain a key driver and must be taken into account when developing scenarios that provide plausible images of alternative futures but population must be regarded as more than an exogenous variable. With regard to the use of population projections as an input for the set of natural science models within IMPETUS, multi-way linkages between population change and other elements of the analyzed system must be recognized, and a systemic view of the linkages is therefore needed (Lutz et al. 2002).

Database and demographic tendencies in Benin

Since all population projections are based on assumptions about future levels of fertility, mortality and migration, a sound understanding of the previous development of these variables is essential. Unlike some neighboring countries, Benin has never been the destination of major international migration. It is thus appropriate to take a national data basis for population projections. Demographic data are available through three censuses conducted in 1979, 1992, and 2002 by the *Institut National de la Statistique et d'Analyse Ecconomique* (INSAE), the national office for statistics (INSAE 1993, 2003a). In 2002, the year of the last national census, Benin had 6.8 million inhabitants (INSAE: 2003a).

These census data give evidence on current tendencies of demographic variables, which are used as input data for population projections. Fertility has declined from 1982, with 7.10 children per woman, through 1992, with 6.1, to 2002, with 5.55 children per woman (INSAE 2003b:40); a decline of 1.55 children per woman over a period of 20 years. Fertility rates are higher in rural areas in North Benin compared to urban areas and the South of the country. Life expectancy has been increasing slowly from 1992 to 2002, from 54.20 to 59.20 years. It is highest for women in urban areas (64.23 years in 2002) and lowest for men in rural areas (57.33 years in 2002). The annual growth of life expectancy between the two censuses is 0.49 years (INSAE 2003b:73). In general, these data show a quite clear picture of the current demographic trends, which will determine the demographic development in the near future.

In the African context, most of these data have comparatively good quality, but this varies for the different variables and their spatial and administrative dimensions. Data on the number and sex of inhabitants have acceptable accuracy up to the level of the small subunits (*arrondissements*). More complex data on fertility, mortality, ethnicity or national migration are less reliable and have to be used with much caution below the regional level of the departments.

Population projections

A population projection is a "best-guess" calculation of the number of people expected to be alive at a future date, based on what is known about the current population size and the expected development of births, deaths, and migration. Population projections should not be treated as forecasts, but as provisional calculations based on certain known or assumed relationships. Therefore, when these relationships change, so should the projections that are based on them.

There are many significant demographic and social trends that need to be tracked carefully into the future. Only then can population projections be useful for a variety of purposes, most commonly as a basis for planning the future demand for infrastructure and public services (Wilson and Rees 2005). In the case of the scenario approach within IMPETUS, population projections are required as an important input for various models, for example in order to illustrate potential future deforestation rates resulting from a growing use of fuel wood or clearing during agricultural colonization processes and its impact on the hydrological cycle.

Methodological approach

In order to provide population projections at different spatial scales with the time horizon of 2025, a two-stage approach was pursued: For making projections for the whole country on the administrative level of *départements*, the demographic model DemProj was applied. Since small population size and limited data availability create methodological problems for small-area projections, a small-area projection refinement model was developed for the smaller administrative units (*communes* and *arrondissements*) that combines extrapolation of growth rates and of percentage shares of the subunits relative to the projected data on the department level.

The computer program DemProj was developed within the POLICY Project of the American development agency USAID, which mainly supports family planning and reproductive health programs. It is a freeware program used worldwide by professionals for making population projections for countries and regions. DemProj calculations are based on the standard cohort component projection, which subjects all cohorts to mortality and migration assumptions on an annual or five-year basis, applying fertility assumptions to women of reproductive age. It was developed by Whelpton (1936), has been formalized and refined ever since (Leslie 1948; Rogers 1966, 1986; van Imhoff 1990) and is used today for country projections by national (Shaw 2004) and international organizations (United Nations 2004).

DemProj projects the population for an entire country or region by age and sex, based on assumptions about fertility, mortality, and migration. A full set of demographic indicators can be displayed for up to 50 years into the future. The model requires the following inputs, which were provided by INSAE:

- *Pop5(a,s): Population by five-year age groups (a) and sex (s) in the base year*
- *TFR(t): Total fertility rate by year*
- *ASFD(a,t): Distribution of fertility by age by year*
- *SRB(t): Sex ratio at birth by year*
- *LEB(s,t): Life expectancy at birth with AIDS by sex and year*
- *Model life table*
- *Migration(a,s,t): Net in-migrants by age, sex and time*
- *The population is projected by age and sex for ages 0 to 79 as*
  Pop(a,s,t) = Pop(a-1,s,t-1) + [migration(a-1,s,t-1) + migration(a-1,s,t)]/2 – deaths(a,s,t-1,t)

As already pointed out, population projections are always based on assumptions about fertility, mortality, and migration. These assumptions should be carefully considered and require profound knowledge about the full range of national and international policies that impact these demographic parameters directly: policies as expressed in laws and in official statements and documents, operational policies that govern the provision of reproductive health services and family planning programs, policies affecting gender roles and the status of women as well as policies in related sectors, such as education and spatially differentiated development planning. Moreover, population projections for Benin consider national projections that include assumptions about the future course of TFRs and life expectancy, national population goals expressed in crude birth and death rates or contraceptive prevalence rates, recent trends and international experience as well as socioeconomic development trends and population program efforts. The qualitative decision-making procedure for making assumptions about future rates of fertility, mortality, and migration in Benin was mainly based on an intensive exchange with INSAE staff in several workshops. During these workshops, the assumptions based on the evaluation of policies, and the other above-mentioned parameters were discussed and compared to the ones developed from INSAE. The important advantage of this approach was the opportunity to access the knowledge of INSAE demographers, who are in regular discussions with multiple stakeholders and experts about their own assumptions for population projections.

Since population projections are always set on possibilities for the future and no one can be certain about the assumptions in the projection, it is highly recommended to produce several projections with different variants of each assumption so that the range of plausible projections can be determined. According to the scenario development within IMPETUS, three different projections were developed for the national and the department levels that reflect scenarios B1, B2 and B3 and their respective storylines (see Fig. III.16). For example, the average life expectancy in the *département* Borgou was 54.1 years for men and 59.61 for women. Taking into account published national projections, national life expectancy goals and national and international policies that impact mortality, such as expansion of basic health care infrastructure in rural areas, HIV/AIDS programs, vaccination campaigns and anti-malaria programs, the following assumptions were made: According to the "positive" Scenario B1, life expectancy increases significantly by 2025 to 62.8 years for men and 69.7 for women. This assumption reflects political stability, economic growth and a substantial improvement of living conditions. For the B2 scenario, life expectancies of 56.1 (men) and 62.8 (women) were assumed. This very slight increase, which is even below the average increase between 1992 and 2002, reflects the failure of national and international policies due to political instability and economic decline. The life expectancy assumptions for the B3 scenario were 60.2 (men) and 66.1 (women), which mirror the persistence of current trends: political stability, but fragmented economic development and a modest improvement in health care and living conditions.

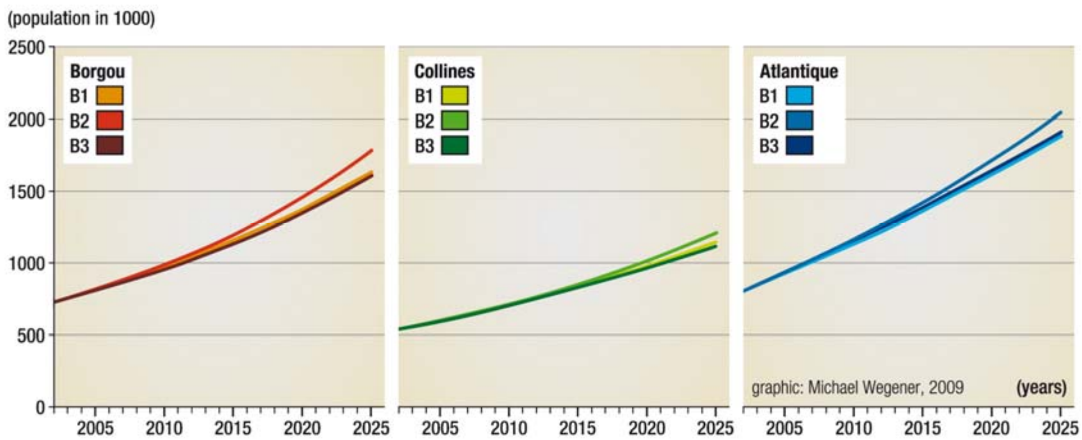

Fig. III.16: The projections of three *départements*: Borgou, Collines and Atlantique (2002-2025).

As already stressed above, most projection techniques remain unsatisfactory for small areas due to poor data availability (Klosterman et al. 1993). Since the population projections are based on assumptions on future levels of fertility, mortality and migration, it is necessary to have sound data on past and present levels of these indicators. As this has proven to be extremely difficult in small areas within developing countries like Benin due to the lack of reliable data, the standard cohort component projections were only made on the level of the *départements,* and a small-area projection refinement model was applied in order to obtain coherent cross-scale projection data on population sizes at different administrative levels. The model combines mathematical extrapolation of past growth rates (Pittenger 1976) and of the subunits' shares relative to the *département* population (Wademnbere Mugumbu 2001). The small-area populations are calculated by the mean values of the extrapolated growth of each subunit and their extrapolated relative shares in the base year applied to the projected data on the level of the department. The mean values are then converted into percentages and applied to the projected *département* data. The great advantage of this rather simple model is that on a low-quality data basis, both projected data on the higher administrative level (the subunit's share of it) and current local demographic tendencies (growth rates) are incorporated and cross-scale coherency is achieved. At the same time, it permits the display of demographic dynamics within the *départements,* which is evidenced, for example, in the case of the suburban commune Abomey-Calavi (Fig. III.17), which will become entirely part of the Cotonou agglomeration by 2025 according to all three scenarios, with a population that will grow from 307,745 in 2002 to more than 1.1 million in 2025. Tchaourou, a rural commune in the *département* Borgou, will have more than doubled its population by 2025, while the population growth will be lower in the commune of Dassa. The charts for the three communes show, however, that the differences between the three estimations (B1, B2 and B3) remain small.

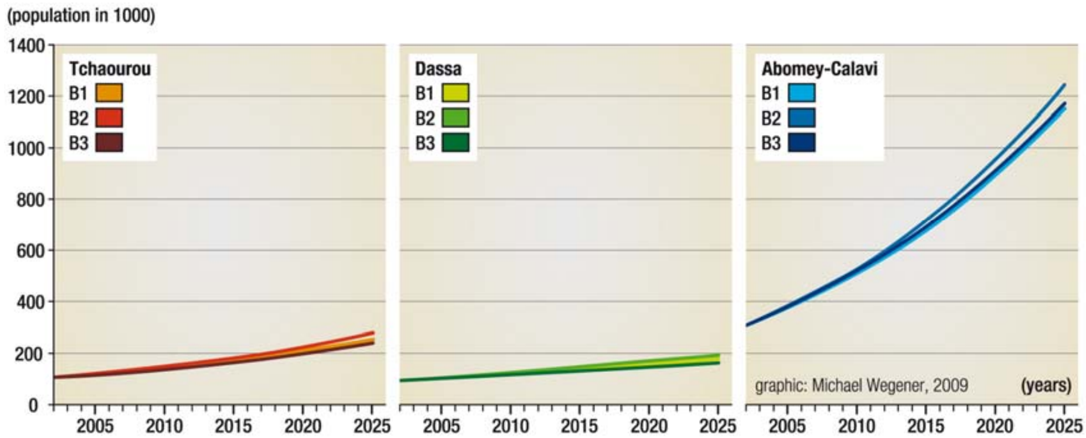

Fig. III.17: The projections of three communes, Tchaourou, Dassa and Abomey-Calavi (2002-2025).

Conclusions

The projections reflecting the three scenarios B1, B2 and B3 are three plausible variants of future demographic development in Benin. The relatively short projection period of 23 years from 2002 to 2025, however, gives little opportunity for plausible antithetic demographic projections. Furthermore, the antithetic settings of fertility and mortality lead to a certain assimilation of the projected population. For the scenario B1, fertility is assumed to decline, while life expectancy is supposed to be extended. For the scenario B2, in turn, fertility is supposed to increase and life expectancy is expected to decline. The consequence is that in terms of total population, the two projections are not as different as one might expect. In 2025, the *département* Borgou, for example, will have a slightly higher population according to the projection B2 (1,779,852) than according to the variant B1, with 1,627,625 inhabitants, and the *Business as Usual* projection B3, with 1,608,618 inhabitants. The interesting differences instead concern the age structure of the population. On a longer time horizon, however, the impacts of different projection variants will become more evident.

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IV Themenbereiche in Benin / *Benin and its Subject Areas*

Under the present climate conditions, physical water scarcity does not appear to be a major limiting factor for food and livelihood security in Benin. Rather, the fast demographic growth arising from high fertility rates and immigration causes a high pressure on natural resources such as soils, forests, water, and biodiversity and challenges the assurance of food security and economic development. The projected climate warming and drying trend occurs in addition to these developments. In parts of the sub-humid tree savannah of Central Benin, particularly in the *Haute Vallée de l'Ouémé* (HVO), farmland expanded considerably at the expense of natural forests during the IMPETUS project period 2000–2009. In the HVO, some of the highest population growth rates in Benin in excess of 5% p.a. also occurred due to immigration from Nigeria and from the Atakora mountain area in northwest Benin. The increasing population and the prevailing extensive, labor-intensive cropping and animal husbandry systems were the major drivers of the rapid land use change that was monitored by IMPETUS in the HVO. Migrants were strongly involved in the process of agricultural colonization. In some villages in the HVO, rural migrants without secure land rights already constitute the majority of the population.

In a way, the recent described strong population and environmental changes made the HVO an ideal study region to investigate the impacts of Global Change on the regional and local scales. Furthermore, the low level of fertilizer use and the high mobility and adaptive capacity of the local people offers a large potential to ensure food security and economic development in the region while at the same time preserving the still relatively abundant resources. The situation in the lower Ouémé catchment is quite different. Here scarcity of arable land and high degradation of soils in the densely populated littoral already causes difficulties in generating an adequate food supply. In a multidisciplinary approach, the disciplinary models developed, adapted, calibrated, and validated for the HVO and the entire Ouémé catchment were used in 19 problem clusters that were stratified into the five subject areas: "Food security", "Water related problems", "Land use and land cover", "Society", and "Health". Within the problem clusters, projections of the development of food, land, and water resources, as well as of public health aspects were performed for the coming decades using the IMPETUS socio-economic and climate scenarios (see Chapter III.1). The realization of such projections and the identification of appropriate management strategies are facilitated by implementing the models and survey results in easy-to-use Decision Support and Information Systems (DSS and IS, see Chapter II).

In Chapter IV.1, the recent and future adaptive potential of Benin's cropping and animal husbandry system under the projected population and Climate Change is discussed. One salient conclusion using the agro-economic model BenImpact is that subsidization of fertilizer use and promotion of measures to increase the use of organic matter and leguminous crops in staple food production by small-scale farmers are worthy of consideration to cope with demographic growth and a potential drying trend. This is based on the assumption that labor and land scarcity is not expected to be a limiting factor in Central Benin in the next two decades or so. Chapter IV.2 discusses the impacts of the projected climate and land use changes on surface runoff, soil erosion, and renewable water resources in the Ouémé catchment using the hydrological model UHP-HRU

(Ultimate? Hydrological Model – Hydrological Response Units), the model system SWAT (Soil Water Assessment Tool), and the water management model WEAP (Water Evaluation and Planning System). One outstanding finding pertains to the fact that the number of months when the domestic, industrial, and agricultural water demand is not met in the Ouémé catchment increases from eight months per year in the period of 2002-2014 to ten months per year for the period of 2015-2025. This clearly indicates the need for improvements in access to surface and groundwater resources in this sub-humid country to avoid periods of local water stress.

Projections of land use and land cover changes using the model LUMIS (Land Use Management and Information Systems) for the HVO with the IMPETUS socio-economic scenarios are highlighted in Chapter IV.3. In this contribution, the consequences of the construction of a road on the conversion of forest to agricultural land are exemplified as an IMPETUS intervention scenario. The following Chapter IV.4 sheds light on how the coexistence of modern and customary land rights causes legal pluralism and legal uncertainty. As a consequence, land conflicts emerge, the purchase of land is problematic and property rights are unevenly distributed. An important and not well-recognized consequence has been the inhibition of agroforestry, and the plantation of cashew in particular, by traditional land owners in large parts of Central Benin because trees are seen as property symbols in large parts of West Africa. Background information on property use and water management at the commune and village level is given in the information system LISUOC (Livelihood Security in the Upper Ouémé Catchment). The last section Chapter IV.5 is dedicated to the future spread of malaria in Benin and West Africa and the chemical, bacteriological, and microbiological contamination of drinking water in the HVO. In the latter context, the information system SIQeau (*Système d´Information Qualité de l´eau*) has been established that contains, amongst others, information on the present drinking water sources in the HVO. The future malaria prevalence is assessed using the Liverpool Malaria Model (LMM) and the IMPETUS climate scenarios. A pertinent finding is that the epidemic malaria belt in the Sahel shifts southward to southern Niger and that the malaria season in Benin might become shorter in the near future due to an overall drying trend.

IV.1 Ernährungssicherung / Food Security

Introduction

The sub-humid savannah of Benin is characterized by fast demographic growth caused by high fertility rates and immigration from both the densely populated coastal areas and the resource-scarce Sahelian zone. This demographic development contributes to high pressure on the natural resources such as water, soils, and biodiversity, and results in high deforestation rates, decreasing soil fertility and conflicts over water and land. Future climate change may aggravate the problem. As a matter of fact, agriculture is the most important source of both income and food in Benin. Ensuring food security and economic development without compromising the natural resource base is therefore an important concern for policymakers on the national and local level.

Farming systems in Benin

Benin has a multitude of farming systems varying in time and space according to local climate, dominant soil types, and land availability. The farming systems in Benin are mainly determined by demographic (scarcity of land), economic (transformation and marketing of agricultural production) and environmental (land degradation, rain variability) factors.

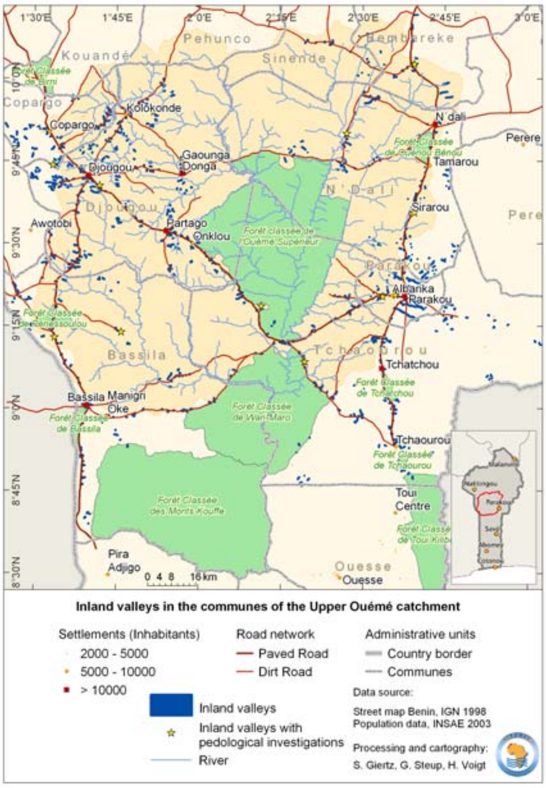

Fig. IV.1.1: Surveyed inland valleys in the communes of the Upper Ouémé catchment.

Demographic expansion and migratory movements have changed conditions for cropping most substantially during the last five decades. The management of idle or fallow land has changed even more dramatically. What used to be the major source of soil fertility restoration has been gradually impoverished by both shorter fallowing periods and by abusive bush fires. Due to climatic and demographic differences Benin hosts three different types of production systems according to the classification scheme of Ruthenberg (1980): shifting cultivation, bush-fallow systems, and systems with permanent production. After Mulindabigwi (2006), the farmers distinguish four types of fallow: (1) Seasonal fallows (6 to 12 months), which are fallows of some months, (2) Short-term fallow (1-2 years), which is often due to shortage of manpower, (3) Medium-term fallow (3-6 years), which is a planned fallow, dominated by grasses and small bushes and (4) Long-term fallow (more than 6 years).

One strategy to reduce at least temporarily the pressure on the upland areas is to exploit the, until present, unused lowlands ("inland valleys"). Inland valleys offer extensive, relatively unexploited potential for agricultural production due to their higher water availability, lower soil fragility and higher fertility compared to the upland areas. In order to evaluate the agro-potential of inland-valleys of the region, a detailed field survey of physical and socio-economic properties of inland valleys was carried out in the communes of the Upper Ouémé catchment. The inventory is part of a multi-level approach using field surveys, GIS, remote sensing and an interdisciplinary modelling to evaluate the agro-potential of inland-valleys. The results are implemented in the information system BenIVIS available for decision makers in Benin.

During this survey, 817 inland-valleys were located in the target region with a total surface of 5563 ha. Fig. IV.1.1 shows the mapped inland-valleys. 536 of the surveyed inland-valleys are already under use, but often only a small part of the inland-valley is cultivated. Fig. IV.1.2 shows the percentages of cultivated and uncultivated inland-valley areas per commune for rainy and dry seasons. Especially in the loosely populated communes in the south of the HVO (Bassila, Tchaourou) the exploitation rate is low. In communes with a higher population density and a high degree of soil degradation like Parakou, Copargo and Djougou the exploitation rate is already above 60% of the potential available inland valley surface. The main crops are rice (62%), yam (17%) and maize (6%). In the dry season the cultivated area remains below 20%.

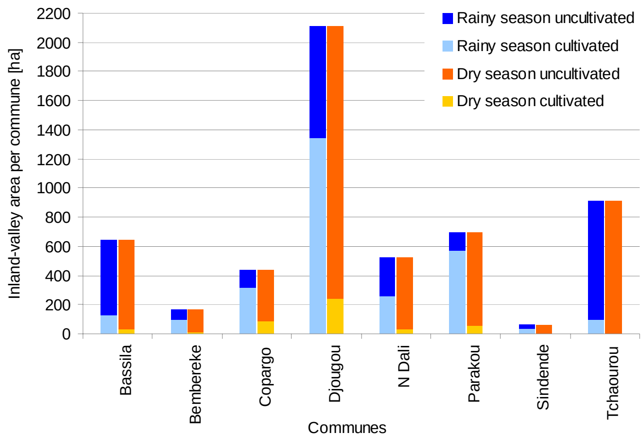

Fig. IV.1.2: Cultivated and uncultivated surveyed inland valley area per season and commune.

Crop productivity in the Ouémé catchment as affected by changes in climatic and management conditions

The high pressure on the natural resources in Benin results in high deforestation rates, in loss of soil fertility, and in conflicts for water and land. Traditional farming systems are characterized by capital-scarce low-input agriculture. As they result in soil degradation, and due to poor knowledge about and lacking access to modern technologies, this lowered agricultural productivity. Soil fertility restoration relies almost entirely on the capacity of the fallow period to replenish the nutrient stocks in the soil. Fertilizer use is restricted to areas with intensive cotton production. Mean input of mineral nitrogen, the most limiting nutrient, into cropland was about 9.23 N in kg ha^{-1} a^{-1} in 2002 (FAOSTAT Online Database) as compared to 60 kg ha^{-1} a^{-1} in 2000/01 in

Europe (EFMA, 2008). Hence, present productivity depends of the quality of the fallow vegetation and on the duration of the fallow period.

The technically most efficient alternative to maintain soil fertility is to increase the amount of mineral fertilizer applied per hectare of cropland and to extent the proportion of cropland where mineral fertilizer is used. Multi-site field trials in the Upper Oueme basin showed the variability of mean yields of maize due to application of different combinations of organic amendments with moderate rates of NPK mineral fertilizer (60 kg ha^{-1} N, 40 kg ha^{-1} P_2O_5) (Dagbenonbakin 2005). This variability of yield effects was due to the heterogeneity of soil and rainfall distribution, and the variable nutrient content of the organic materials. On all sites, mineral fertilizer alone increased crop yields compared to the control treatments; however, the increase was not always significant. However, with higher rates of mineral fertilizer, long-term maize and cotton yields are stabilized significantly above the control without mineral fertilizer (Gaiser et al. 1999).

Simulations at a larger spatial and temporal scale with the SDSS PEDRO (see Chapter II.8) indicate that the effect of moderate rates of mineral fertilizers is beneficial, when applied prudentially. The yield ratios for all crops simulated over the five departments in the upper and middle Ouémé basin are above one, which demonstrates the beneficial effect of the regular supply with major nutrients (Tab. IV.1.1). The effect is highest with rice and lowest with cassava, which received the lowest rate of mineral fertilizer (7.5 kg N/5.5 kg P_2O_5/11.5 kg K^2O ha^{-1} a^{-1}) in the simulations.

The yield ratios increase over time, mainly because of the yield decrease of crops cultivated without fertilizer. This deteriorating effect of reduction of fallow-cropland ratio on nutrient availability may aggravate with the expected climatic changes. Fig. IV.1.3 shows the change in mean annual precipitation in the Upper Ouémé basin in the last four decades (1960-2000) compared to downscaled climate scenarios A1B and B1 (see Chapter III.2).

Table IV.1.1: Evolution of simulated yield ratios[1] of six major crops in Benin in a climate scenario from 2000 to 2025.

	2005	2010	2015	2020	2025	Mean
Maize	1.46	1.49	1.73	1.75	2.08	1.70
Rice	1.56	1.95	2.37	2.91	3.55	2.47
Cassava	1.06	1.04	1.12	1.07	1.17	1.09
Cotton	1.34	1.39	1.76	1.85	2.12	1.69
Peanuts	1.22	1.18	1.30	1.41	1.52	1.33
Sorghum	1.11	1.10	1.20	1.20	1.35	1.19

[1] Yield ratio = crop yield with fertilizer/crop yield without fertilizer

The mean annual precipitation over four decades in the past was around 1100 mm, although high inter-annual variability occurred within these decades. It is expected that the inter-annual variability will at least persist, but in addition it is likely that the mean annual precipitation may decrease by about 30%. In parallel, until 2050 the mean annual temperature in climate scenario A1 and B1 is expected to increase by 8.3 and 6.4% respectively.

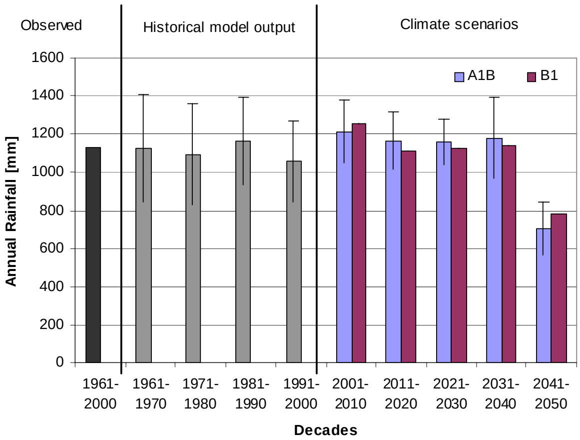

Fig. IV.1.3: Mean annual precipitations in ten years periods in the past and in the future according to dynamically downscaling of output from the GCM ECHAM5 for climate scenarios A1B and B1.

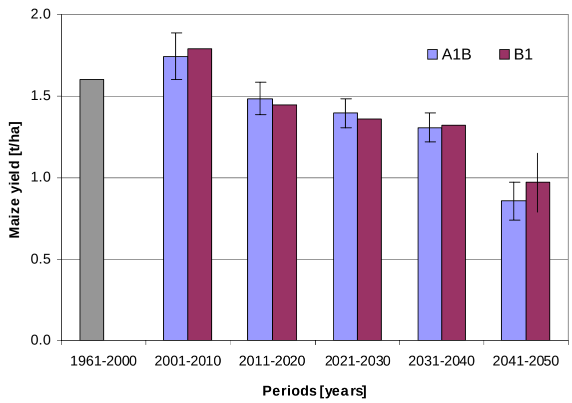

Fig. IV.1.4: Simulated yield response of maize to changes in rainfall and temperature conditions for climate scenarios A1B and B1.

The consequences on crops with high demands for sufficient and evenly distributed rainfall like maize will be detrimental. According to long-term simulations until 2050, the increasing soil moisture deficit may reduce the average yield levels of maize by up to 75% in the decade 2041-2050 (Fig. IV.1.4). In addition, the production risk is likely to increase expressed by the higher inter-annual variability in this decade (larger error bars in Fig. IV.1.4).

Economic scenarios for food markets and land use

Land use change in Benin predominantly occurs as an expansion of agricultural areas. To assess the sustainability of current trends, long-term resource-economic simulations have been carried out with the model BenIMPACT. Scenarios are based on assumptions regarding important exogenous drivers such as population growth or changes in non-agricultural income.

The baseline scenario of BenIMPACT assumes that agricultural land use is expanded primarily due to high population growth causing lower opportunity costs for farm labour. At the same time, the consumption of food commodities increases because of population growth and growth of per-capita income. Income consists of two endogenous elements, farm incomes and incomes from off-farm labour, and an exogenous non-agricultural income component which is assumed to increase at 1 percent per capita and year in real terms.

Fig. IV.1.5 compares regional food energy balances for the base year 2000 and the simulation year 2025 in the baseline scenario. In 2000, most regions in Benin produced slight crop energy surpluses. However, the existence of densely populated deficit regions such as the southern communes of Cotonou, Porto-Novo and Mono leads to an almost balanced national food energy equation of 5 kCal per capita and day (surplus). Given a continuation of current trends in population and income growth, these surpluses would significantly decrease in most regions. Even though most regions would still produce food energy surpluses, the national balance would turn into a deficit of 490 kCal per capita and day, which is almost one-fifth of the average individual food energy requirement. The projection for the expansion of cropland use is shown in the next graph (Fig. IV.1.6). Crop areas will almost double in the central parts of Benin, i.e. the departments of Borgou, Collines, and Donga. The two northern departments of Alibori and Atakora will also see considerable increases in land use. The southern departments of Benin, however, will increase land use much less, mainly because opportunity costs of land will increase there much more strongly due to higher land scarcity and more competition from other uses (e.g. settlements) in the south.

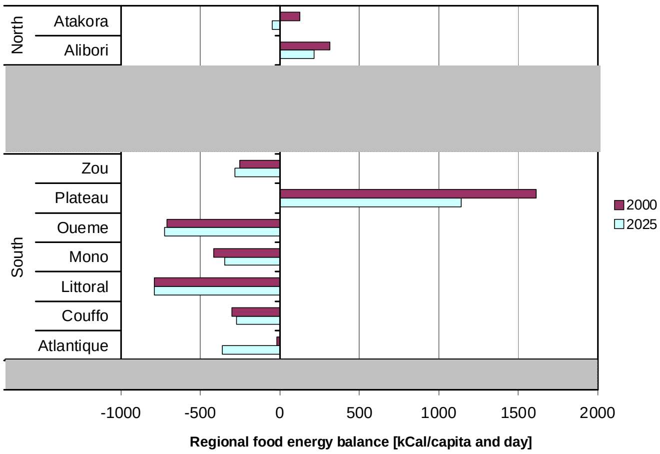

Fig. IV.1.5: Regional food energy balances in the BenIMPACT baseline scenario, 2000 and 2025.

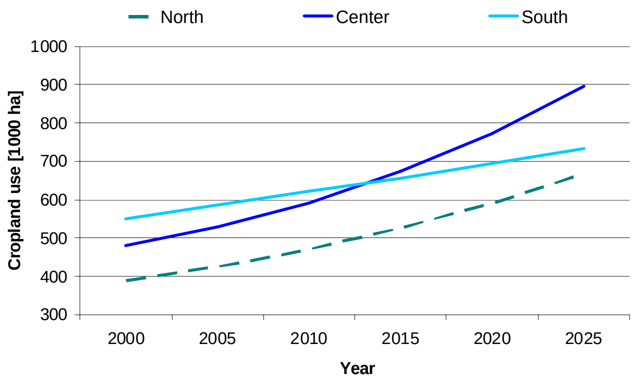

Fig. IV.1.6: Expansion of cropland use for larger regions, 2000 to 2025.

Increased use of mineral fertiliser - higher food security?

The very low increase in the productivity of staple crops explains largely the increased dependence of African countries on food imports. The use of mineral fertiliser may dramatically improve the food balance of many countries and result in lower food prices, higher food supply, and consumption, improved food security and better nutritional status.

As cotton accounts for roughly 90 percent of Benin's export earnings, government interventions in that sector were aimed at ensuring a constant and sufficient supply of cotton to the local cotton processing plants (Adégbidi et al. 2000). As a consequence of the fertiliser quota system, it is indeed plausible that national and regional consumption of fertilisers is closely associated with the importance of cotton production.

To simulate the impact of changes in fertiliser policy on cropping patterns and commodity markets in Benin, the use of fertiliser had to be made into a decision variable. The economic rationale of farmers to use fertiliser depends on the crops' yield response to fertiliser, which calls for the implementation of a yield response function. This was achieved by estimating quadratic approximations of results delivered by the EPIC simulations described above. The final step necessary to implement the endogenous yield functions into BenIMPACT was to calibrate crop-specific use of fertiliser for the base year. This was achie1ved by simultaneously choosing profit-maximising levels of N-application and 'base yields' (yields that would prevail without the use of fertiliser).

Our scenarios assume that fertilizer use in Benin is constrained by import and domestic taxes. To demonstrate the medium-term effects of tax exemptions for fertiliser – corresponding to an indirect subsidisation of fertiliser use – on farm production and food markets in Benin, counterfactual simulations have been carried out, covering the period between the year 2000 (the base year of BenIMPACT) and 2025. The *baseline scenario* assumes that the *current policy scheme will be continued* throughout the simulation period, with fertiliser quotas increasing in line with regional cotton areas. The *counterfactual scenario* envisions that the *tax exemptions* granted to fertiliser for cotton production are made universal to all fertiliser used. This means that from 2010 onwards fertiliser prices are exempt of taxes and VAT.

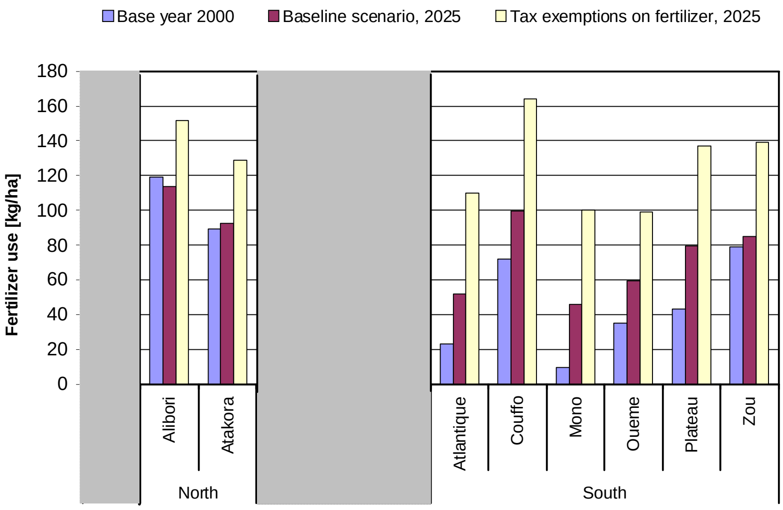

Fig. IV1.7: Regional use of fertilizer in 2000 (base year) and 2025 (baseline scenario and the tax exemption scenario).

Under the tax-exemption scenario, yields for the majority of crops would increase substantially up to one-third of their level in the year 2000. The impact of those productity gains will reduce land consumption and positively affect market balances, and food consumption.

Fertiliser use per unit of area in individual crops and in total develops quite differently in the two scenarios. Tab. IV.1.2 shows national averages of fertiliser use for individual crops, while Fig. IV.1.7 compares total regional use across scenarios. For crops, increases in fertiliser use correspond to the yield increases shown above. The regional distribution of changes is interesting, as it shows that without policy change, use will not change significantly over the observed period. The baseline scenario exhibits slight decreases in the North caused by declining relative profitability of cotton production, and minor improvements in the South. National use per hectare is projected to increase by only 2.5 percent in average over the entire period. General tax exemptions will increase fertiliser use substantially, particularly in southern regions where quotas of subsidized fertiliser had been small.

Table IV.1.2: Crop-specific use of fertiliser (NPK) in kg/ha in the two scenarios.

	Base year 2000	Baseline scenario, 2025	Tax exemptions on fertiliser use, 2025
Maize local	0.0	1.5	27.2
Maize improved	12.2	19.2	84.6
Rice	86.2	87.0	139.6
Sorghum	0.0	0.0	0.0
Cassava	113.0	160.9	196.6
Yams	0.0	0.0	0.0
Pulses	17.1	19.8	97.3
Peanuts local	70.3	66.3	146.3
Peanuts improved	120.6	110.5	174.6
Cotton	213.9	193.4	303.8

Table IV.1.3: Surplus or deficit for all regions of Benin [in 1000 t and in percent of domestic use].

	Base year 2000		Baseline scenario, 2025		Tax exemptions, 2025	
	in 1000 t	% of use	in 1000 t	% of use	in 1000 t	% of use
Rice	-150.0	*-85.0*	-367.0	*-89.7*	-351.1	*-87.6*
Cassava	162.7	*15.4*	146.8	*6.7*	161.0	*6.9*
Maize	81.2	*21.1*	-185.6	*-20.5*	-5.8	*-0.6*
Yams	28.0	*3.1*	-60.2	*-3.1*	-48.2	*-2.5*
Sorghum	-34.1	*-19.5*	-170.4	*-40.0*	-160.2	*-38.2*
Pulses	-6.8	*-9.1*	-86.6	*-45.3*	-44.6	*-23.4*
Peanuts	27.0	*31.8*	-25.0	*-12.4*	37.1	*18.7*
Cattle meat	0.08	*0.4*	-13.2	*-26.2*	-11.7	*-23.8*

As price signals by increased demand will remain weak under an unchanged currency regime, closing a future food gap for Benin will require productivity gains. The scenario with tax exemptions for fertiliser shows that deficits for most products would be much smaller as compared to the baseline scenario, most prominently for maize and yams, but also for rice and cassava (Tab. IV.1.3).

Conclusions

Increasing population and land scarcity are the two most important driving factors influencing the food balance of Benin. Despite the velocity of both trends, no absolute land scarcity is likely to emerge in Benin in the next two decades, and thus no scarcity of food. Nevertheless, shifting the focus to the different degrees of marginality of current and potential cropland, it becomes obvious that in the semi-arid North as well as in the humid south marginality will become more severe, as well as around urban agglomerations. These results indicate that the suitability of land to produce food will be most threatened where it is most needed to provide the local population with staples. The aim has to be to find a compromise between spreading the burden of increasing demand for cropland among regions and types of landscape while conserving existing cropland reserves like forests, savannahs, and wetlands (*bas-fonds*) as far as possible.

In their quest to achieve food and income security for their families, farmers themselves constantly adjust to changes in the ecological and economic environment: in the face of deteriorating prices for cotton, the areas for maize and cassava were increased. But also cashew trees, producing a cash crop, are increasing their share in cultivated area. However, adjusting crop mixes and rotations alone will not suffice to make up for land scarcity, a prominent symptom for which is an ever shorter fallow period in more densely populated areas. With land becoming scarce, soil fertility will have to be sustained by increased use of organic matter, leguminous crops, and mineral fertiliser. The profitability of all of these 'modern' options is still precarious, preventing sufficient levels of utilisation to stabilise soil fertility, land use, and food supply. Labour is still too cheap to reward labour-saving technical innovations. As long as slashing forest is still cheaper than using fertiliser to arrive at the same harvest amount, little change of current trends can be expected. Sustained higher economic, income, and wage growth would, other things kept equal, contribute a lot to reverse current trends of excessive cropland expansion in Benin.

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IV.2 Wasserbezogene Probleme / *Water-related Problems*

Scenarios of land use and climate change – impact on hydrology and water availability

Environmental changes like land use and climate change have a considerable impact on the water cycle. For future water resource management it is important to assess the possible impacts of these changes on the water resources for a longer time horizon of 20-50 years. As a prerequisite, the models used should be validated for the region and tested for the modelling purpose (land use change, climate change). For the Ouémé catchment the hydrological model UHP-HRU was used in an interdisciplinary modelling approach (Giertz et al. 2006). The new model version (UHP-HRU 2.5) was validated for different sub-catchments under different land use scenarios for both dry and wet periods. The spatially distributed results have shown that the model results, particularly surface water run-off, are highly sensitive to changes in land use. Here, the impact of land use change on the hydrology of the Upper Ouémé catchment is analysed using spatially distributed land use change scenarios by Judex (2008). The impact of climate change on future water availability was simulated for the two IPCC scenarios A1B and B1 for the whole Ouémé catchment for the period 2001-2049 using downscaled results of the REMO-model.

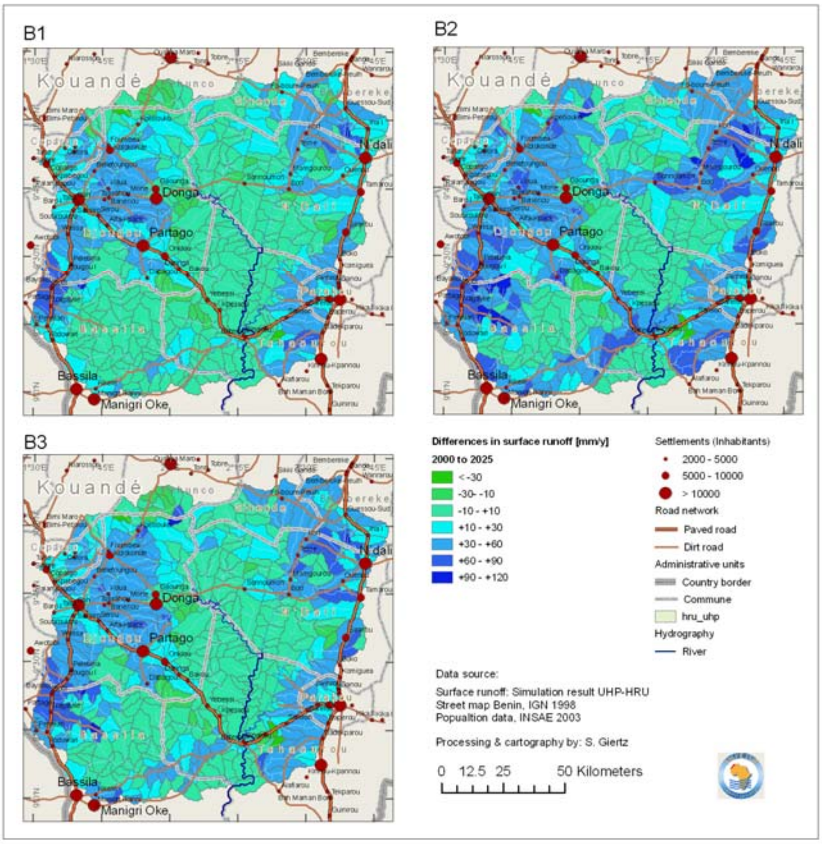

Fig. IV.2.1: Change in surface runoff from 2000 to 2025 for the socio-economic scenarios B1, B2 and B3.

Fig. IV.2.1 shows the differences in surface runoff from 2000 to 2025 for the three socio-economic scenarios. All scenarios show an increase in surface runoff in the region of Djougou and along the roads from Djougou to other villages. Especially southwards (direction Bassila) the surface runoff enhances in all scenarios. Moreover, the surface runoff increases on the eastern border of the catchment around the cities Parakou and N'Dali. The highest rise is visible in scenario B2 (mean surface runoff of 93 mm in 2025 compared to 59 mm in 2000).

The impact of climate change on water availability was simulated for the whole Ouémé catchment using the results of the regional climate model REMO (Paeth et al. 2009). Current climate models cannot correctly represent the climatology of rainfall, but they are more reliable in terms of atmospheric circulation and thermodynamics. To address this, so-called Model Output Statistics (MOS) are applied in order to adjust the REMO rainfall data (Paeth et al. 2009) followed by a statistical downscaling approach to create artificial station data for each rainfall and climate station in Benin. The evaluation of rainfall amounts and intensities by Hiepe (2008) shows that the post-processed REMO-results are suitable for hydrological impact studies.

The climate scenarios based on the post-processed REMO-results were simulated with the calibrated UHP-HRU 2.5 model for the Ouémé-Bonou catchment (49,285 km^2) for the period 2001–2049. As the annual variability of rainfall in the region is rather high only the results of semi-decades or decades were analyzed. Fig. IV.2.2 shows the development of the rainfall and the total renewable water as mean for semi-decades for the climate scenario A1B. Tab.IV.2.1 summarizes the water balance for the reference period 1980-1999 and the five decades of the climate scenarios A1B and B1.

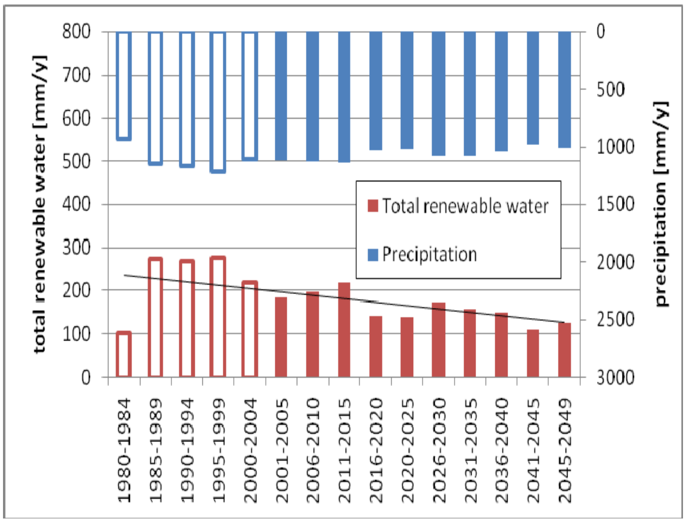

Fig. IV.2.2: Development of precipitation and renewable water resources (= total discharge + groundwater recharge) in the Ouémé-Bonou catchment (49,285 km^2) for the climate scenario A1B simulated with UHP-HRU (mean for of the three ensemble runs; filled bars: UHP-HRU model results using post-processed REMO climate and precipitation data; unfilled bars: UHP-HRU model results using measured climate and precipitation data).

The results of the hydrological model reveal that the amount of renewable water decreases during the period 2001-2049 in both scenarios. The trend is more extreme in climate scenario A1B. In the latter the discharge decreases by about 44% in the last decade as compared to the reference period, and a reduction of 52% was determined for the recharge. In the B1 climate scenario, the decrease still amounts to 25% for discharge and 31% for recharge. In Fig. IV.2.3 the spatial patterns of the total renewable water are shown for the periods 1980-1989 and 1990-1999 and 2040-

2049 for both scenarios. The results demonstrate that in the northern parts of the catchment the spatial pattern remains constant despite a decrease in the amount of water during the period of 2040-2049 as compared to 1980-1989 and 1990-1999.

Table IV.2.1: Mean simulated annual water balance for the reference period and climate change scenarios A1B and B1 in the Ouémé-Bonou catchment (49,285 km^2). The results are averages of the three ensemble runs for each climate scenario.

	Precipitation [mm/y]	Etpot [mm/y]	Etact [mm/y]	Discharge [mm/y]	Recharge [mm/y]
observed					
1980-1999	1118	1727	908	131	99
Scenario A1B					
2001-2009	1125	1953	921	105	84
2010-2019	1091	1971	907	105	83
2020-2029	1035	1988	895	83	58
2030-2039	1078	2010	909	96	70
2040-2049	997	2053	877	74	47
Scenario B1					
2001-2009	1159	1915	908	132	103
2010-2019	1072	1973	916	90	67
2020-2029	1069	1972	912	91	67
2030-2039	1079	1992	908	99	72
2040-2049	1065	2021	897	98	68

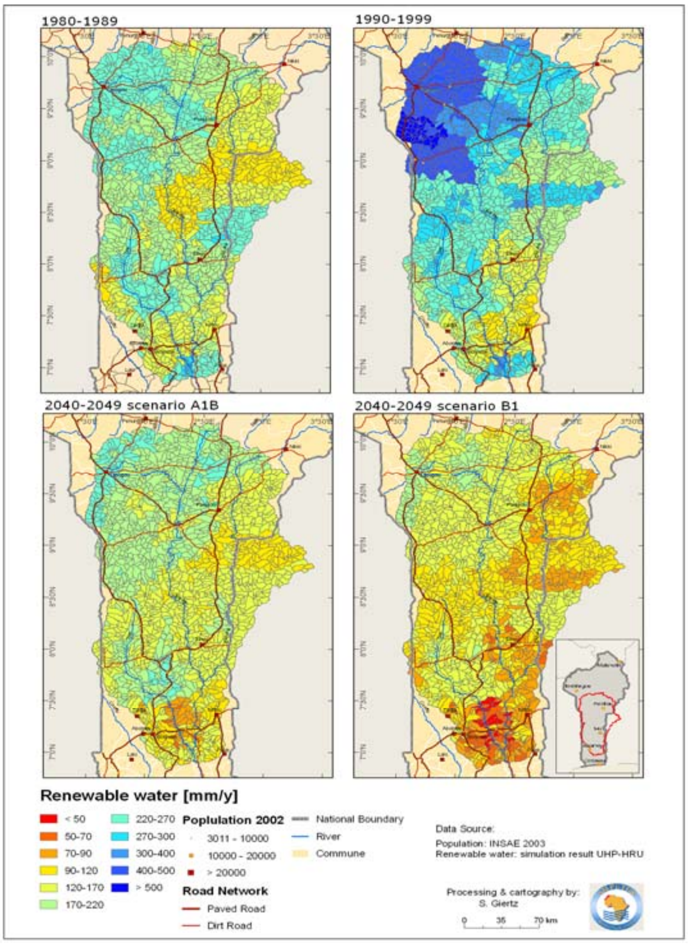

Fig. IV.2.3: Mean total renewable water resources (= total discharge + groundwater recharge) for the decades 1980-1989, 1990-1999 and the period 2040-2049 (scenarios A1B and B1, mean for the three ensemble runs).

Balancing future water availability and demand

Managing water resources efficiently requires a well informed water policy. The information provided to decision- and policymakers should therefore be structured in a way that benefits the decision making process. The presentation of water availability and demand in a water balance suffice theses requirements (Sakthivadivel 2006). Therefore the results of the hydrological modelling were combined with socio-economic water demand data within the Integrated Water Resource Management (IWRM) model WEAP (Water Evaluation And Planning system). IWRM and its models are useful tools to improve water management practices and to increase water security.

The WEAP system is a demand-, priority-, and preference-driven water planning model. It aims at closing the gap between water management and watershed hydrology by addressing water demand and availability at the same time. With its focus on scenario analysis, WEAP allows simulating changes in supply and demand structures, hereby discovering potential shortages and the impacts of different management strategies or development paths on water availability (Yates et al. 2005). The principle algorithm of WEAP is a spatially resolved water mass balance calculated on a monthly basis. At every node and link in the system, water supply and demand are required to be balanced. Water demand nodes primarily stand for domestic, industrial or agricultural demand sites as well as flow requirements for hydropower. Groundwater aquifers, reservoirs, and rivers are represented as supply nodes which are connected to the demand sites via linkages. The spatial resolution of the nodes and links is applicable to all scales; however, the resolution highly depends on the questions being asked and data availability.

To analyze water demand and supply on the catchment level, it was necessary to disaggregate the information available on the commune level to account for different development paths, and to aggregate, on the other hand, information on the village level to achieve a manageable amount of data. The aggregation took into account the affiliation to a commune and to a rural or urban district. This approach more than recognizes the recommendations by Wallgren (2006) who suggests applying water demand models on a more local scale.

Benin’s water demand has been studied and characterized comprehensively by Schopp et al. (2007), Hadjer et al. (2005) and Gruber et al. (2009). Based on their findings and taking into account the different development paths of the three societal, economic, and ecological scenarios applied by IMPETUS, water demand scenarios for each sector were developed (Höllermann 2008, Höllermann et al. 2009).

Population growth and economic development are major determinants for future domestic water demand. The combination of population scenarios by Heldmann and Doevenspeck (2008), national plans concerning the improvement of the water infrastructure and minimum water requirements set by the WHO (2003) allowed outlining different water use scenarios. The scenarios of the industrial water demand are based on survey (Schopp et al. 2007) and regional forecast studies by Shiklomanov (1999) and Rosegrant et al. (2002).

National agricultural extension plans (MMEH, 2000), average population growth rates, and expert interviews by Schopp and Kloos (2006) and Gruber et al. (2009) form the basis of the agricultural water demand scenarios. As a result of the different water demand scenarios demand is continuously increasing over the simulation period. Hereby, scenario B1 shows the highest growth rates (Tab. IV.2.2). Water demand particularly increases for the domestic and agricultural demand sites. Another important user of water is livestock, while industrial water use is projected to remain insignificantly small. While domestic and industrial water demand do not vary throughout the year, agricultural water demand shows a distinct monthly variation influencing the intra-annual demand. Therefore, the water demand is highest from December to March during the dry season and decreases with the start of the rainy season. The increased water demand during the dry season intensifies the competition about scarce surface water resources.

Table IV.2.2: Total water demand [Mio. m^3] for different socio-economic scenarios and for time periods up to the year 2025. Note that the year 2002 is the base year for reference.

Year	Socio-economic scenario B1	Socio-economic scenario B2	Socio-economic scenario B3
2002		44.47	
2005	51.77	46.73	50.34
2010	64.84	50.96	60.27
2015	81.77	56.48	71.64
2020	100.92	63.44	83.85
2025	126.06	72.30	98.23

The water balance for the Ouémé-Bonou catchment was calculated for the period from 2002 to 2025, with 2002 as the base year for reference (Höllermann 2008). The results show that the different climate scenarios A1B and B1 have a strong impact on water availability. A significant decrease in catchment inflow is observed for the period of 2015 to 2025 in climate scenario A1B, while this effect is mitigated in climate scenario B1. The decreasing inflows affect the accessible groundwater storage. In general, the surface water inflow into reservoirs varies during the year with no or hardly any inflow from November to May. This typical annual change decreases the storage to a minimum in the months of February to June. With the onset of the rainy season the storage recovers with its maximum in October. Less catchment inflow aggravates the refill capacity of larger reservoirs. Furthermore, growing water demand increases the pressure on reservoir water. This increase is more significant in climate scenario A1B under economic scenario B1, presenting the highest water extraction from reservoirs.

According to the effects of the climate scenarios, water scarcity is highest in the last decade of the study period. This becomes visible from the over-average increase in unmet demand in the period of 2015 – 2025 (Fig. IV.2.4), especially amongst demand sites relying on water from rivers or reservoirs. As the availability of surface water follows a monthly variation - due to the changes from rainy to dry season - the shortages solely occur during the dry season. While the effects of the dry season with unmet demands can be found for about 8 months per year in the period of 2002 – 2014, these effects extend to 10 months per year for the period of 2015 – 2025 (Fig. IV.2.5).

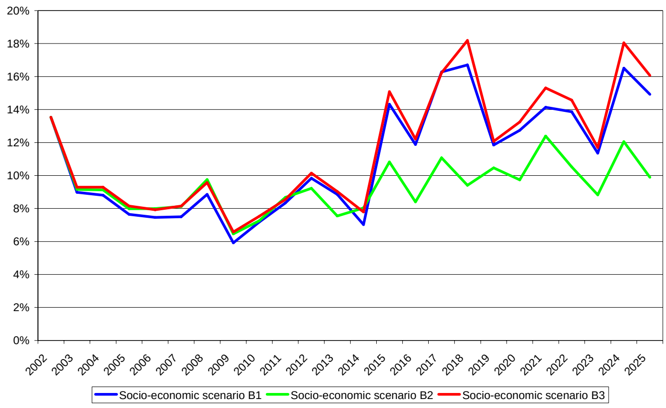

Fig. IV.2.4: Unmet water demand of the Ouémé-Bonou catchment in percent of total water demand for the socio-economic scenarios B1, B2 and B3.

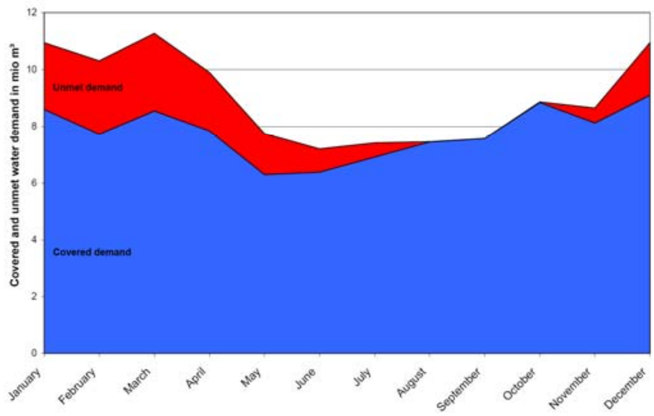

Fig. IV.2.5: Monthly water demand of the socio-economic scenario B1 averaged over the period 2015-2025. The water demand is distinguished into covered (blue) and unmet (red) demand.

Soil erosion by water in the Upper Ouémé catchment considering land use and climate change

Soil erosion by water deteriorates soil quality and can heavily affect crop productivity in low input farming systems. The extent of soil erosion in Central Benin is expected to increase in the future due to rapid cropland expansion and more frequent and intense extreme rainfall events due to climate change. On the other hand, mean annual rainfall may be reduced. Erosion models are important tools in order to study the effects of land use and climate changes on erosive and hydrological processes at the regional scale. After successful application of the time-continuous, semi-distributed SWAT model (Soil Water Assessment Tool; Arnold et al., 1993) to analyze current hydrological and erosive processes in the Upper Ouémé catchment, future scenarios could be analyzed (Hiepe 2008).

For the three land use scenarios (L1 to L3), land use maps for the years 2005, 2015 and 2025 were used from the model CLUE-S model (Judex 2008) which reflect an expansion of the cropland area by 51-108% until 2025 depending on the scenario. The scenarios assume different cropland demands resulting from the extent of population growth and crop intensification. Land use change scenarios are combined with climate scenarios built on results of the regional climate model REMO (Paeth et al. 2009). The scenario results were compared to the results of the original model parameterized for the period 1998-2005.

In the following, the effects of the land use, climate change, and combined scenarios for the Upper Ouémé catchment are summarized. All land use scenarios increase sediment yield and surface runoff significantly in the Upper Ouémé catchment. All other components of the water balance remain nearly constant (see Fig. IV.2.6, left). By 2025, the sediment yield increases by 42%, 95% and 60% for the land use scenarios L1, L2 and L3, respectively. These trends are even more pronounced in the SW of the catchment, where cropland is rapidly expanding. However, the sediment yields in these areas do not yet reach the currently high sediment yields around Djougou and Parakou.

The climate scenarios (see Fig. IV.2.6, right) and combined scenarios for 2001 to 2025 lead to a more differentiated picture between the scenarios. As a result of decreases in mean rainfall of 3% and 4%, the climate scenarios B1 and A1B reduce water yield by 6% and 12% and sediment yields by 5% and 14% in the Upper Ouémé catchment. Despite higher temperatures, actual evapotranspiration remains nearly constant. Surface runoff decreases for the A1B climate scenario and remains nearly constant for the B1 climate scenario.

In the combined scenarios, the negative trend for water yield due to climate change is slightly weakened due to land use change. In contrast, sediment yields increase for nearly all combined scenarios, by up to 31%, showing the dominance of land use change in most parts of the catchment. In contrast, surface runoff and water yields decrease strongly in the Djougou region which is most affected by climate change and less affected by land use change.

Fig. IV.2.7 shows the spatial patterns of sediment yield for the "business as usual" land use scenario and one of the combined scenarios. In addition to the current hotspots of soil erosion in the Djougou and Parakou regions, as well as along the main roads Djougou-Beterou-Parakou, new hotspots arise in the southern and north-eastern parts of Upper Ouémé the catchment corresponding to the current deforestation hotspots in the catchment.

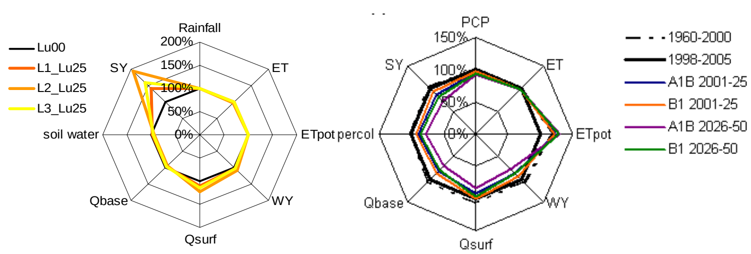

Fig. IV.2.6: Components of the water balance in the Upper Ouémé catchment for the land use scenarios (left) and the climate scenarios (right) relative to the original model (1998-2005).

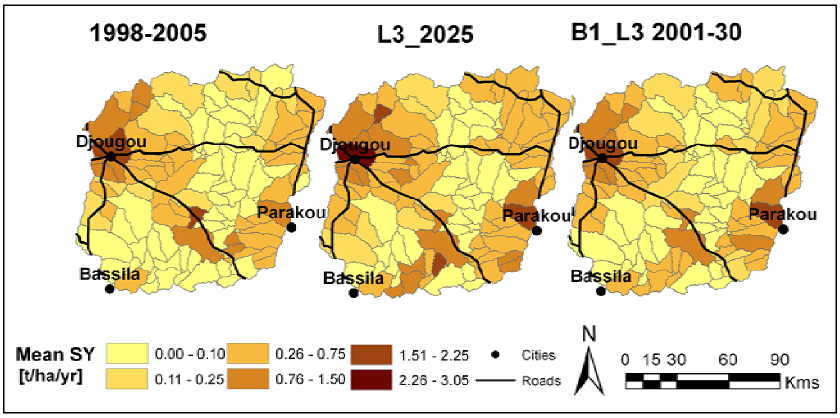

Figure 7: Mean spatial distribution of sediment yield for the original model, the land use scenario L3_Lu25 (Business as usual) and the combined scenario B1_L3 2001-30.

Conclusions

Scenarios were computed for the Upper Ouémé (soil degradation and water availability) as well as for the whole Ouémé basin (water availability and water demand). The scenario analysis for the Upper Ouémé catchment indicates increasing sediment yields and decreasing water yields for the period 2001-2025. However, the variability within the Upper Ouémé is large. In sub-basins with a high potential of cropland expansion (e.g., S and SW of the catchment), future sediment yields will be driven by land use change and may therefore strongly increase. In sub-basins with low potential of cropland expansion and strong reductions in rainfall (e.g., Djougou region), future sediment yields may decrease. While cropland expansion in the entire Upper Ouémé catchment may slow down in the next decades, climate change impacts will increase with time and show higher variation among the scenarios.

Although Benin does not belong to the physical water scarce countries, seasonal shortages are common. Facing the impacts of climate change, an assessment of the national water resources is an important step to assure a sustainable water resource management and to improve access to drinking water. Therefore, by linking the WEAP water planning model with the hydrological model UHP-HRU, the current and future water balance of Benin's largest catchment Ouémé has been modelled taking into account the possible impacts of climate and socio-economic change. Results show, that the competition for water during dry season will increase. Improving the access to groundwater is an alternative; however, financial and institutional constraints hinder such a development. Furthermore, declining catchment inflows aggravate the situation and require an adapted groundwater management.

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IV.3 Landnutzung und Landbedeckung / *Land Use and Land Cover*

Introduction

Human induced land surface change and anthropogenic climate change are the most important forces currently affecting the earth's ecosystem (Ojima et al., 1994, Vitousek et al., 1997, Foley et al., 2005; Lambin & Geist, 2006). Land cover is a critical component of all ecosystems. In addition, changes in land cover have definite and predictable impacts on climate (Pielke & Avissar, 1990; Bounoua et al., 2002; Feddema et al., 2005; Hegerl et al., 2007), hydrology (Defries & BELWARD, 2000, Costa et al., 2003; Giertz et al., 2005; Lehrter, 2006), biodiversity (Dirzo & Raven, 2003) and biogeochemical cycles (Melillo et al., 2003, Fisher et al., 2006). Such changes are largely due to anthropogenic causes. The land is also influenced, however, by natural drivers, which may be cyclical and can change abruptly. Such cycles and abrupt changes in natural land conditions may have ominous or even catastrophic consequences in fragile ecosystems. The assessment of land cover and land use change is essential for a comprehensive analysis of land use systems, because the temporal dimension leads to an accurate understanding of the development paths. Land cover and land use changes are closely linked semantically and land use changes usually result in direct and predictable land cover changes.

Land use and land cover data are often inadequate, incomplete, or non-existent in less developed countries; in Africa, especially, often only fragmentary official land statistics are kept. During the Sahelian, droughts a number of scientific studies of land use were undertaken in Africa to explore climate-related issues and resulting land degradation. A great deal of environmental and social data is available from this work (Reenberg, 1997; Mortimore & Adams, 1999; Hammer, 2001; Warren, 2002). There are, however, comparatively few studies focused on the West African "Middle Belt"; the zone of dense woody savannas between the Atlantic coast and the Sahel (Lambin et al., 2003). In addition, the latter stated in their study that very little quantitative land use and land cover data are available for any African dry forest and/or woodland savanna environments. This region is the focus of the IMPETUS project.

Land evaluation of the biophysical resources in Benin

Benin's population is expected to increase from under 8 million people to over 14 million by 2030 (INSAE, 2003a). In large parts of the region, there will be a critical need for additional agricultural land, as agriculture will continue to essential for the socio-economic system of the country. Crucial decisions regarding the location and extent of agricultural expansion in the region will be necessary and must consider a number of important regional environmental and socioeconomic characteristics. One elementary basis for sustainable land use is a detailed knowledge about biophysical resources for land use and their evaluation. The identification of marginal, i.e. vulnerable sites is therefore of specific importance to preserve land resources for agricultural production in future periods. Agricultural marginal sites are perceived as vulnerable, low-potential areas characterised by various environmental constraints, which are particularly prone to land degradation (CGIAR TAC, 1999; Lipper et al., 2006; Röhrig, 2008).

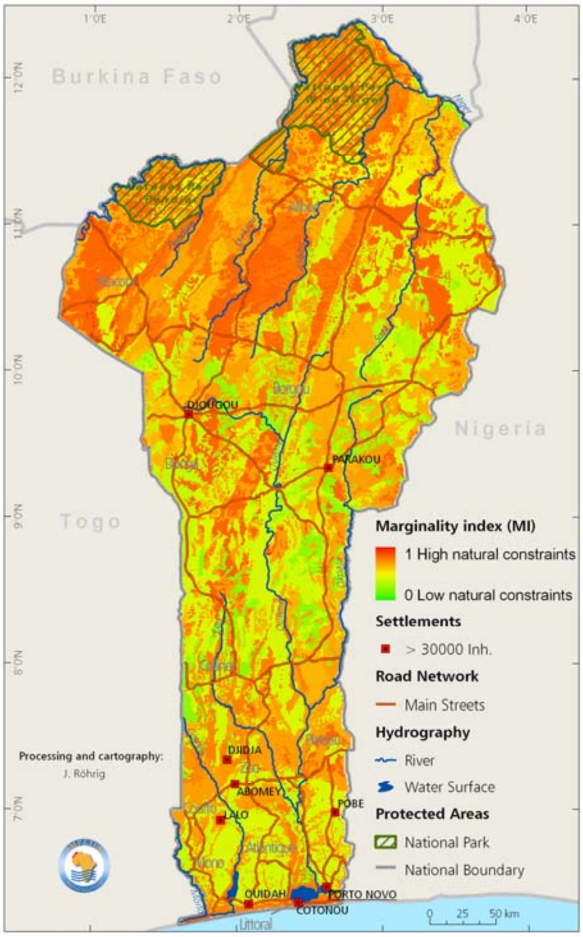

Fig. IV.3.1: Biophysical conditions in Benin based on the marginality index (MI) (1960-2000).

The marginality index for agricultural land use, which was introduced by Cassel-Gintz et al. (1997) on a global scale, was used to identify marginal sites and to evaluate agricultural land resources of Benin (cf. Röhrig, 2008; Röhrig & Laudien, 2009). For the assessment of the index, several biophysical factors limiting agricultural production under low capital input (e.g. restrictions due to temperature and aridity, precipitation uncertainty, poor soils and the risk of erosion) are analyzed using a fuzzy-logic-based algorithm (cf. Cassel-Gintz et al., 1997; Röhrig, 2008). For Benin, we adapted the global approach to the national scale and determined the marginality index (MI) in a spatial resolution of 1km x 1km (see Fig. IV.3.1) (cf. Röhrig & Laudien, 2009). The index reflects the degree of natural constraints (1: high constraints and 0: no constraints) facing agricultural land use, and thus the degree of natural marginality.

Fig. IV.3.1 illustrates the marginality index (MI) determined for the period between 1960 and 2000. In general, the current biophysical conditions for agricultural land use are moderate in Benin, demonstrated by an average MI-value of 0.6. Hardly one fifth of all sites are favourable (MI-value ≤ 0.3) for cultivation of the main crops (e.g. cotton, maize, manioc, rice, sorghum and yams). Crucial natural constraints are soil fertility, rainfall variability and length of the growing period.

Own scenario analyses indicate that climate change will greatly affect the biophysical conditions in Benin (Röhrig, 2008). Particularly temperature will become a more severe constraint. In addition, the length of growing season will slightly decrease (by about ten days) due to a decline of rainfall. In addition, the variability of the growing season will increase. The date of its start and end will therefore become more variable, causing greater insecurity and risk for farmers.

Land Use and land Cover in central Benin

In several regions within Benin, agricultural production is currently limited in southern Benin by high population density and generally by low soil fertility (Igue et al., 2000; Mehu, 2000). In contrast to the densely populated southern Benin, the central part of the country has a relatively low population density and sufficient land remains for agricultural production. In this area of the country, however, illegal logging is widespread and many farmers migrate to new areas as soil quality degrades on existing plots. These processes lead to important land-use and land cover changes (Doevenspeck, 2005). Unfortunately, exact figures on land use dynamics and their spatial patterns in Benin are currently not available. Our current research using remote sensing analyses will generate quantitative data on land use changes ongoing in the country.

LUCC Modeling using LUMIS

The implementation of a new land use and land cover model LUMIS for the Upper Ouémé Catchment is based on the CLUE (Conversion of Land Use and its Effects) model concept after Veldcamp and Fresco (1996). LUMIS is a spatially explicit, raster-based land use change model. For IMPETUS, some model components have been modified and downscaled to the regional Judex (2008) and to the local scale (Orekan, 2007). On the regional scale, the parameterization and validation of land use model was performed for the period 1991 to 2000, where detailed land use information were available from satellite remote sensing data. In the following, the main outcomes of the land use modelling are given. Detailed information about the model and its components are given in Verburg et al. (2002) or Judex (2008).

The parameterization of the model and the calculation of the probability maps using logistic regression are the basics of LUMIS. Therefore a set of explanatory variables or driving forces have to be identified in order to explain and statistically describe the spatial pattern of land use and land use change in the Upper Ouémé Catchment. While some driving forces are directly linked to land use (e.g. precipitation), others affect indirectly land use as it is the case for many socio-economic variables (see Geist et al., 2006). In the context of land use modelling, we call them mediating factors. For the regional scale, our analysis show that the main important driving forces which determine the distribution and change of land use in the Upper Ouémé Catchment are population density, distance to road, distance to settlement/town, protection status of forest, soil suitability for agriculture and relief parameters (e.g. slope).

Using logistic regression based on this set of proximate and mediating factors, the patterns of land use and the spatial occurrence of a particular land use types can be explained. Therefore the existing land use class for a given time period is used as the dependent variable. Logistic regression was successfully performed and used for the dynamic simulations within LUMIS. The accuracy of the logistic regression model was determined using the pseudo-R2 measure after Nagelkerke's and McFadden (Menard, 2002). The conversion from logistic regression results into spatial probability maps for each land use is shown in Fig. IV.3.2. For the land use classes settlement, agriculture, forest and dense savannah and other savannas the maps indicate the probability with which the individual land use exists in 2000.

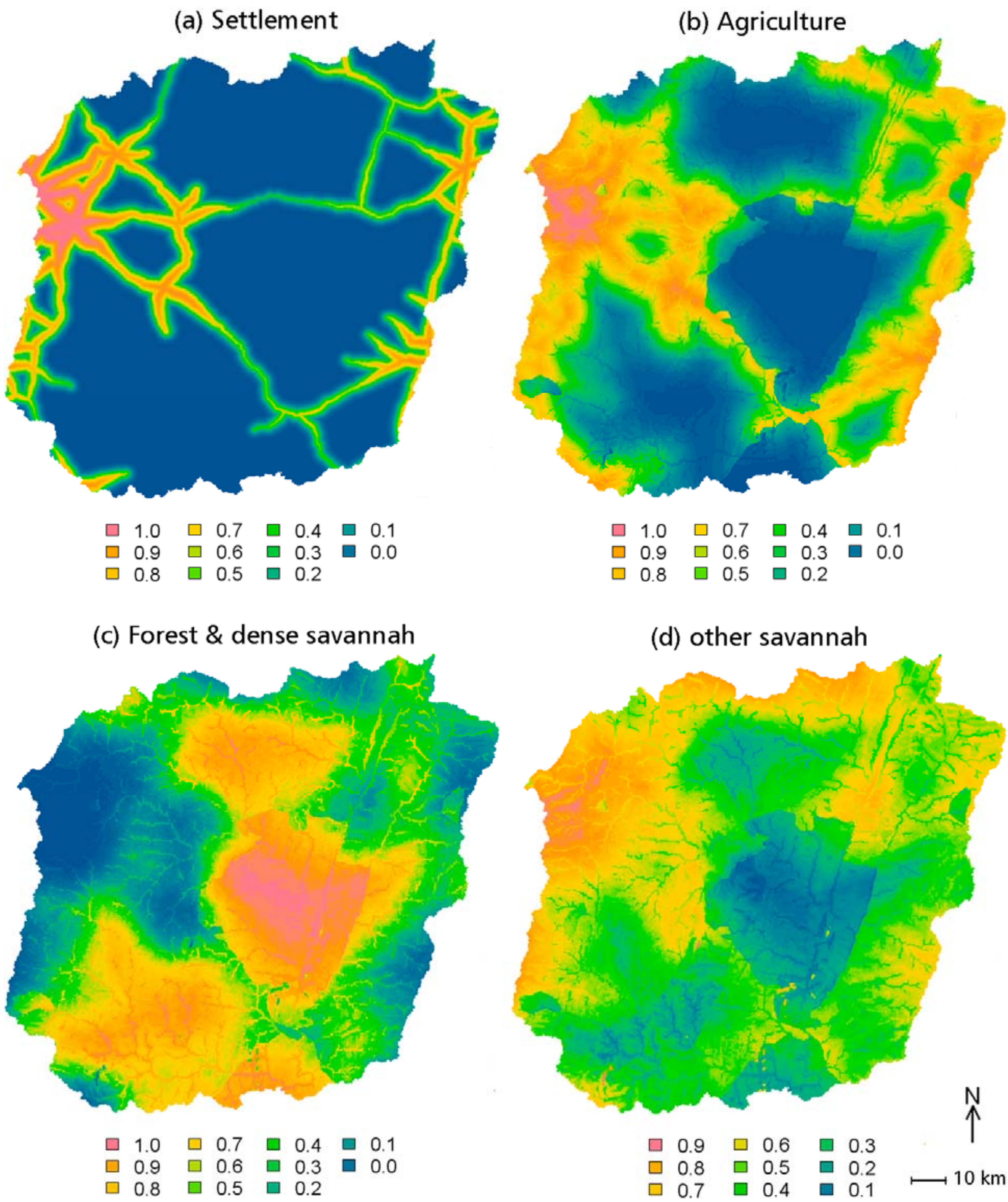

Fig. IV.3.2: Probability maps of the land use classes settlement, agriculture, forest & dense savannah and sparse savannah as calculated by logistic regression. Each pixel indicates the probability with which a certain land use class exists in 2000.

LUMIS was developed and calibrated for the period 1991 to 2000. LUMIS has a temporal resolution of one year and a spatial resolution of 300 x 300 m². The demand for agricultural land was derived from own land cover and land use change analysis between 1991 and 2000. A comparison between the observed land use and land cover (by satellite data) and the modelled land use and land cover (as a result of LUMIS) for the year 2000 is shown in Fig. IV.3.3. The three explanatory variables were population density, distance to road and distance to the next main city (local market).

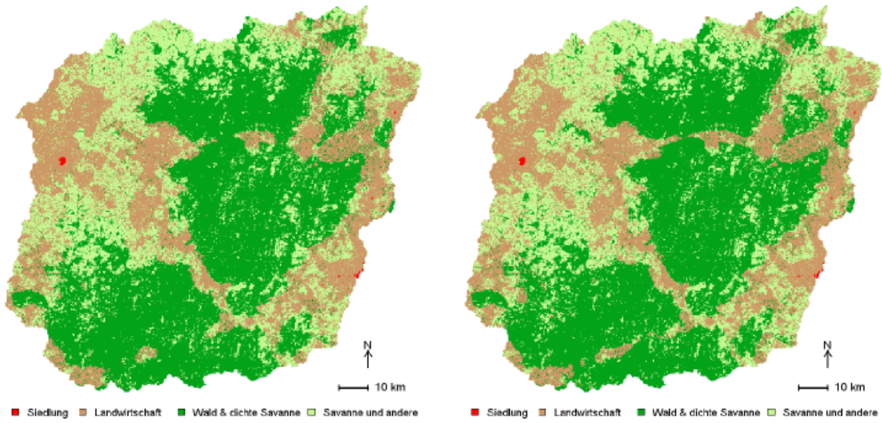

Fig. IV.3.3: Spatial distribution of land use and land cover of the Upper Ouémé Catchment for the year 2000 as derived from LUMIS (left) and from satellite observations (right).

With AUC values (Area under curve) from 0.7 to 0.9 the results of logistic regression and the probability maps of the spatial patterns of land use and land cover demonstrate good model accuracies. For each land use class a different set of explanatory variables was found (cf. Judex 2008). In general, the simulation of the distribution of land use change is largely determined by the existing neighbourhoods. For scenarios of future land use changes plausible assumptions for the changing drivers are therefore crucially important. This is the content of the next chapter.

Scenarios of land use for the Upper Ouémé Catchment until 2025

In order to estimate the possible consequences of future land use changes on food security, hydrology, biodiversity, etc. land use scenarios are fundamental important. To this end, the results of the scenarios can be integrated in decision support systems.

In the following sections, the assumptions and outcome of one IMPETUS-scenario, scenario B1 will be illustrated in more detail. In addition, one complement intervention scenario is presented, which exemplifies the impact of infrastructure changes.

(A) Economic growth scenario (B1)

The scenario B1 assumes economic growth and an anchoring of decentralization, i.e. by improving conditions for political and socio-economic situation. In this scenario, it can be assumed that the functioning of administrative structures and continuity in development cooperation is an extension of (small) agricultural innovations taking place. This allows a higher yield per unit area to be produced; thereby expansion the agricultural land use activities will be reduced. In calculating the agricultural area and population data for the scenario B1, agricultural areas grow no longer exponential, but only linear, as increasing population density of the cultivated land per person is declining steadily. This seems, given the observed strong surface expansion especially in the Upper Ouémé Catchment, not realistic. Therefore, it is assumed that the per capita cultivated area will decrease at a half rate. The assumed progress in resource management is reflected in a reduced loss of forest land for agriculture. Initially, in 2000, nearly 50% of agricultural land expansion was won through deforestation; in 2025 it is only 30%. The settlement area is increasing with the same rate of change to (4.5%) as the positive economic development more attractive jobs in cities.

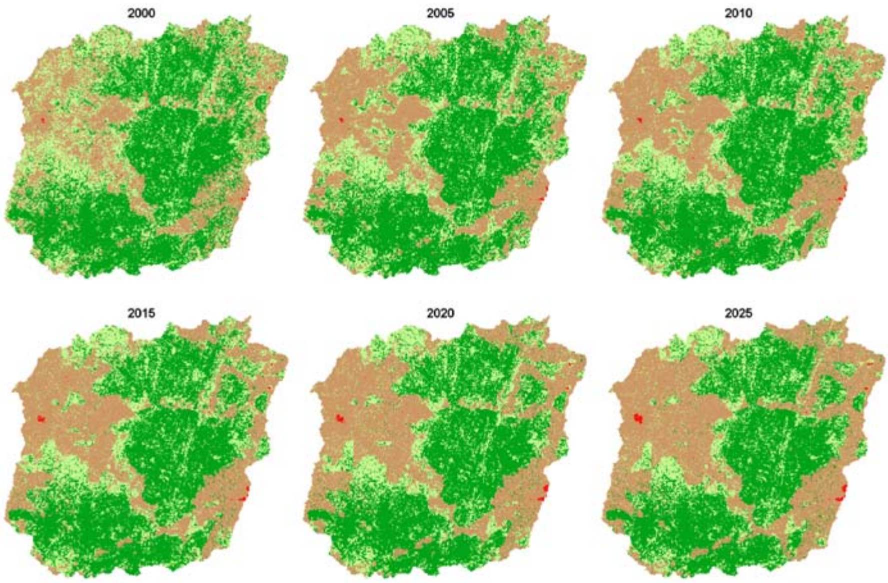

Fig. IV.3.4: Results of the regional land use and land cover model LUMIS for the economic growth scenario B1.

In scenario B1 (Fig. IV.3.4) less forest land will be converted into arable land as it is the case in another IMPETUS scenario B2, economic stagnation. Economic growth has the benefit that new agricultural land will be more developed on existing savanna areas and therefore less pronounced in forest areas. In contrast, in the scenario B2 such forest areas are relatively quickly converted into arable land.

(B) Intervention scenario (B5)

Scenarios can also be used to evaluate the impact of a planning measure on the environment. Therefore, a scenario was developed, that shows the impact of a hypothetical road construction on the land cover change in the Upper Ouémé Catchment (Fig. IV.3.5). In doing so, it was assumed that in 2010 a new road will be constructed between Partago and Dogu. This scenario might realistic, as several meetings with representations of the "Ministère des Travaux Publics et des Transports" documented.

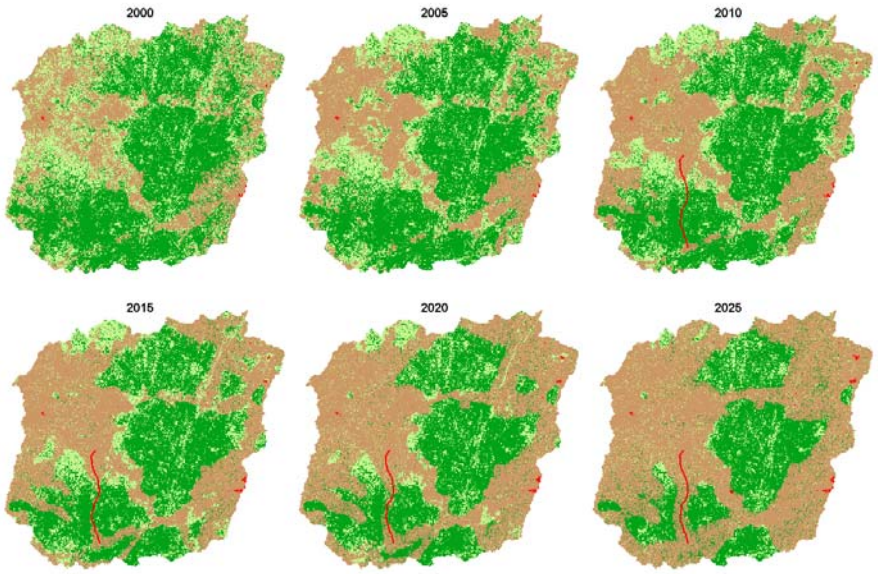

Fig. IV.3.5: Results of the regional land use and land cover model LUMIS for the intervention scenario B5.

Conclusions

Information about land resources supports rational land-use planning a sustainable use of natural and human resources. In this context, the marginality index for agricultural land use was used to evaluate current agricultural land resources of Benin. On a smaller scale, the new land use model LUMIS was used to analyse main driving forces and to simulate different scenarios of possible future land use changes. The results of the dynamic modelling of scenarios depend on the starting conditions and the given space. It appears, however, that different boundary conditions lead to a non-linear evolution of the spatial pattern of land use.

The expansion of agricultural land was the most important land use change and was predominately based on demographic projections, land use intensity and assumptions regarding the use of fertilizers yield calculated. For the initialisation of the model real changes in urban and forest areas were derived from remote sensing based land use classification. The scenario runs from 2000 to 2025. While scenario 1 (B1) has been implemented according to the general IMPETUS scenarios, scenario 5 was based on an exponential population growth and a new road construction. The latter scenario is used as an example of a so-called intervention scenario, and shows the responsible planning authorities possible impacts of various planning variants.

In all scenarios, population growth is the dominant driver, which converts natural land into agricultural land. Deforestation is particularly pronounced in those places where the distance from roads to forest areas is very low and the population density increases. Such "hot spots" of deforestation are found, for example, in the Southwest of the Haute Vallée de l'Ouémé, but also in the northeast in the communities Sinende and Bembereke. An overlay of MI and population density indicates, too that the farmers' decision, where to settle, does not depend exclusively on biophysical conditions. Interviews with farmers of Benin show, however, that the particularly soil fertility is an essential factor on the local scale whether a specific site is used agriculturally or not. Thus, it must be assumed that the spatial resolutions as well as the differentiation of the soil suitability information are too coarse in the land use modeling to illustrate the importance of the factor. Nevertheless, the results of LUMIS contain detailed information regarding the land use dynamics in Central Benin, and the opportunity to demonstrate how spatially explicit data for future land use changes can be obtained. The procedures show good results and can be considered as an important basis for sustainable resource use are used to hot-spots of critical development for early detection of and countermeasures to be able to plan.

On a national scale, analyses based on the marginality index indicate that the expansion of agricultural activities on marginal areas are particularly crucial as they have already resulted into severe land degradation in several regions diminishing the biophysical potential to ensure food security. Hence, particularly precautionary measures and the availability of agricultural consulting agencies are needed to prevent severe land degradation. The establishment of farm advisory centres could assist the farmers in choosing adapted farming systems and suitable crops based on biophysical conditions. Furthermore, regulatory measures should be installed to avoid conflicts between ethnic groups about scarce resources.

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IV.4 Gesellschaft / *Society*

Introduction

This report focuses social, political and economic aspects of change and its environmental consequences in Central Benin. Who are the main actors driving change? What is the role of the local traditions for the over-all tenure system concerning land and water resources in particular? What are local strategies to secure and control natural resources? How do local actors adapt to these conditions of uncertainty in Central Benin? Finally, what are the roles of the state, international donors and the recently created *communes* (municipalities) concerning water and natural resource management in the context of decentralization?

Central Benin, and in particular the Upper Ouémé Catchment, is a rural region characterized by high demographic growth rates, increasing pressure on natural resources, increasing water demand and degradation of soils. Despite high growth rates the population density in the catchment is still below 70 inh. per km^2 which allows at least in some regions long fallow periods and thus recovery of soil fertility. However, the availability of fertile land and water is decreasing due population pressure and possibly also due to climatic changes. This in turn leads to an increase of conflictual living conditions for the concerned population.

Climate and demographic scenarios predict that these processes will be exacerbated in future by e.g. a higher variability of the rainy season and fast population growth driven by agricultural migration (Doevenspeck 2006: 54-55). At the same time, we observe profound political, and socio economic changes in Benin in general and in the project region in particular: democratization and decentralization, changes in land tenure in connection with the new land policy, high dynamics in local tenure systems and in the ethnical and social composition of the population, and reorganization processes in the agricultural export production.

After depicting land tenure and the changing legal and political ramifications of the management of land and water, we will deal with the strongly gendered household economics in the region. We then embark on a critical reflection of most recent legal changes pertaining to land tenure and comment upon their contribution to tenure security. Finally, the Information System LISUOC (**Li**velihood **S**ecurity in **U**pper **O**uémé **C**atchment) is presented, which supports local decision makers through information and data bases on livelihood security, demographic development and water management. Most of the quantitative data presented in this section have been collected in a gender-sensitive and statistically representative survey with 839 women and men in urban and rural areas of 7 *communes* in Central Benin (see Hadjer 2006, 2008). This IMPETUS Survey is also a main basis for the Information System LISUOC and will be discussed more detailed at the end of this section.

Land tenure and risk coping in the Context of National Policies

Land and water resources are the basis for livelihoods in Central Benin, a rural region that has had the lowest population densities in Benin until the 1970ies but which is now characterized by high growth rates and environmental degradation. According to the mentioned IMPETUS statistical representative survey, 65 % of the local population quote cultivation as their main economic activities. Land tenure, the relationship among people with respect to land and water resources, is thus a key aspect of human environmental interactions in the area. Land tenure comprises access to land and water resources, property as well as use rights, transfer and administrative rights. It is composed by a set of rules, which may be written or unwritten, invented by societies to regulate behaviour (see also FAO 2003: 7): In Benin, land tenure is determined by legal pluralism and legal uncertainty through the coexistence of customary land rights and modern land law. In most of the rural areas, like the Upper Ouémé catchment, customary land rights are still dominant.

The customary tenure principles are integral part of the social structure and thus inseparable from social relationships throughout rural West Africa, where land is traditionally seen as a common property resource. Customary land rights are implemented and arbitrated by customary authorities, whose legitimacy usually derives from prior occupancy (principle of the "first comer" or "first clearance") and the magic/religious alliance with the local spirits, or from conquest (Delville 2000: 98; Degla 1998: 59). The customary tenure principles are highly complex, dynamic and varying from one place to another.

In generally, land is not seen as an alienable asset, but rather as means for survival for a kin-group comprising the ancestors, the living and the unborn members, and represents much more than a means of production. Indeed, these customary land rights are not in harmony with the national land legislation, based on the colonial land law, which did not take into account customary land tenure. The national legislation focussed on land registration as individual property including use, administration and transfer rights or on nationalisation of land. The complexity of customary tenure principles, with diverging and contested use, transfer and administrative rights has been disregarded until very recently by the national legislation. The consequence is the current coexistence of modern and customary land rights (Heldmann et al. 2008b:122).

In rural areas of Central Benin, different forms of land access (heritage, purchase, share-cropping, lease, present, loan) exist; only heritage guarantees unlimited and relatively secure land use rights. Legal uncertainty is thus a particular problem for migrants who can't inherit rights to land. They have to loan land from (customary) land owners. In order to avoid eventual future property claims of the migrants, these land owners prohibit them to do any long-term investments like agro-forestry or perennial cultures (Mulindabigwi et al. 2008: 122), because trees and sometimes even perennial cultures are seen as property symbols in large parts of West Africa (e.g. Le Meur 2002; Delville 2000). As shown in Fig. IV.4.1, agroforestry, and the plantation of cashew in particular, is thus prohibited in large parts of Central Benin.

The uneven distribution of property rights is a problem of land tenure in Benin. Besides migrants, also women cannot inherit land and are thus generally excluded from land possession because of the patrilineal system. In some areas of Benin, rural migrants without secure land rights constitute already the majority of the population. If the commoditization of land increases like in South Benin, these people may be deprived from access to credit.

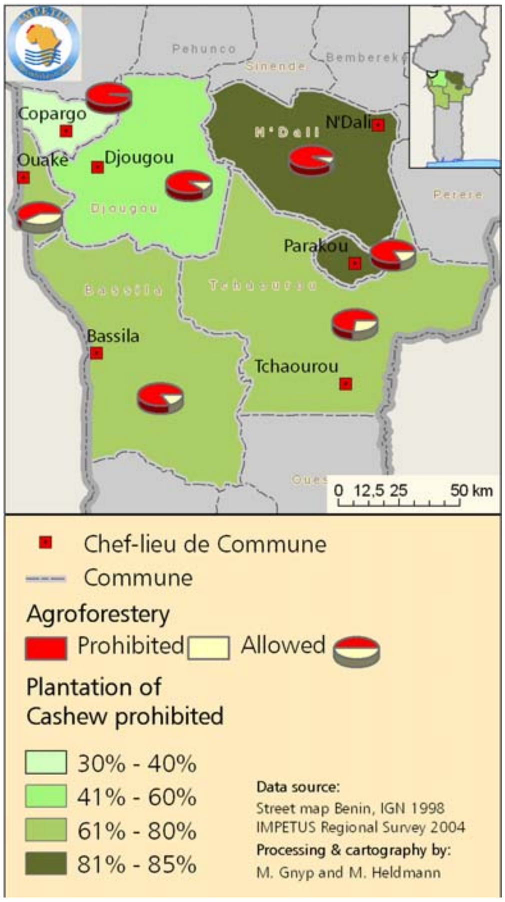

Fig. IV.4.1: Restrictions in respect to agroforestery.

The new rural land law of 2007 tries to meet the major problems of legal pluralism. The new simple rural cadastres on the village level (Plan Foncier Rural) aim to increase legal certainty through a documentation of customary land rights. However, land conflicts are also due to inequalities, and namely the unevenly distribution of land. As long as land is available and as long as degradation is no major problem, open land conflicts remain rare. But in some parts of the Upper Ouémé region, land has already become scarce and degradation affects the agricultural production. Here conflicts over access to land and individualization of land rights – to very different degrees – can already be observed (Mulindabigwi 2006: 145). The inhabitants of the region are used to ensure their livelihoods despite high levels of uncertainty and have developed strategies to cope with it. Case studies in different villages point to contradictory tendencies related to individualisation within one customary land tenure scheme (Mulindabigwi 2006, Doevenspeck 2006).

Coping with risk: Land use and related strategies

Social science research on local livelihoods, adaptation strategies and vulnerability emphasizes the capacities of people to apply innovative risk strategies (e. g. Boserup 1993, Smit and Wandel 2006). Like in many development countries also the rural population of Benin adopts multiple economic activities to cope with uncertainty and seasonality of food supply.

Agriculture constitutes the most important set of activities. This is especially true for the centre and north of Benin where only 39 percent of the population lives in urban areas (INSAE 2003). While cotton production is highly risky due to fluctuating world market prices and changing national regulations, many people assure livelihoods by subsistence agriculture. The fact that agricultural production and the commercialisation of agricultural products are closely interlinked favours intra-household cooperation between men (dominating the agricultural domain) and women (dominating commodity trade in agricultural products at local, national and international level).

The view that women perform the bulk of agricultural work proves untenable for many parts of Benin. According the survey conducted by the social scientists of the IMPETUS team, twice as many men were engaged in cultivation and horticulture than women (Hadjer 2006:176). The survey revealed 1.4 main economic activities per man and 1.6 per woman. Thus, women and men respond to the restrictive access to natural resource due to the marked impact of the rainy and dry season fairly flexibly: many perform several different economic activities in the course of a year in order to support themselves and their families.

Men usually combine agriculture (rainy season) with craft-production or work in the service-sector (dry season). Women frequently generate revenue by a combination of commerce and the transformation of agricultural products into commodities. Only few women officially own land and in some regions 'reaching for the hoe' is taboo. Also trading in agricultural commodities is more lucrative and the incentives to extent agricultural activities are limited. Certainly, motives and reasons for the diversification of income generating activities are multiple (see e. g. Gasson and Winter 1992, Giourga and Loumou 2006). However, people tend to maximize opportunities through diversification in light of uncertainity caused by rain failure or an insecure and limited access to natural ressources.

The high flexibility and mobility of the working population seems to favour a high level of adaptative capacities in case of changes of the social-ecological system. For example, women adapt their transformation activities very creatively depending on demand and supply situations. Therefore, a producer of millet beer or shea butter will reduce her activities in times of water scarcity and switch to other activities as selling shoes or agricultural products.

In Northern and Central Benin, the export-oriented cultivation of cotton constitutes an important acculumation strategy of men despite fluctuating world market prices and structural weaknesses of this still de facto state controlled sector. The one-time payout of high amounts of money adds zest to cotton production. The sophisticated cultivation of the highly vulnerable plant demands time, discipline, calculative capacities, technical know-how and the credits for financial investments such as sowing, pesticide, dung or wageworkers. These conditions involve considerable risk factors such as unforeseen indebtedness and may lead to nutritional insecurity and intra-household conflicts.

The food security of families is particularly endangered when producers neglect subsistence food production at the cost of cash crop production. To the surprise of many small scale cotton producers, earnings are frequently lower than expected. The deception is due to external factors as mainly (1) rain failure causing low crop grow rates and a poor quality of cotton grains or (2) fluctuating world market prices causing low revenues. Moreover, internal factors on the individual level are often ignored, such as (3) false calculations and (4) lack of understanding of contracts and offers of subsidies due to illiteracy. Many farmers miscalculate derivative investment costs as wage labour, bribe or the loan of a pesticide distributor. The resulting unbalance between prospects, arrears and effective gains bring about debt, conflicts and food insecurity (Hadjer 2006: 241ff).

The cotton crop calendar has to be applied strictly. Therefore, expenditure for wage workers is often inevitable. The government promotes parallel production of maize and cotton by all cotton producers to avoid food insecurity. But many farmers prefer to sell the subsidized seeds in need of money and with the aim to reduce the amount of credits. Others practice an extended use of cotton fertilizers in maize production due to the increasing soil degradation.

Where income is irregular and the dependence on external factors like rain is high, precautions have to be taken for times of shortage. The rural and urban population attempts to cope with livelihood risks through complex networks of highly gendered gift exchange. This strategy is maintained equally in urban and rural areas and takes place throughout the year and mainly within extended families (Hadjer 2008a: 117). Exchange occurring outside of familiar borders takes place in a strictly gendered way between neighbors, friends or collegues.

The exchange of agricultural products, objects, money or meals establishes social relationships and dependencies. Female engagement into food exchange is a key-strategy to increase food security. Donations of money constitutes one third of all circulating gifts in the survey region. Indeed, monetary gifts circulate more frequently between men. In urban areas, land access and capacities of storage are scarce. Here, the exchange of agricultural products is realized equally to the gift of money. Generally, women exchange greater numbers of gifts in shorter time intervals with a higher frequency and with a higher rate of reciprocity than men do. In sum, land use and livelihood security are highly linked to gender-specific risk strategies. Agricultural production, the transformation of agricultural products and their exchange prove to be key activities all depending on water and water management systems.

Water Management in times of decentralisation

On the local level, several actors and institutions compete for political power and influence. Some of them gain their influence through customary offices or through derived political or economic power, while others hold an official public office. Besides traditional authorities as informal actors, officials are formally in charge of natural resource management. They are generally supported by international assistance of different donor organisations. In rural Benin these actors are the agents of different centralised public services and the officials of the local districts, the decentralised *communes* that have been created in the process of decentralisation in the 1990s. Although the *communes* hold important legal competencies and responsibilities in the fields of natural resource management and water management in particular, they have neither the funds nor the competencies to assume their responsibilities:

Rural water management is particularly affected by this struggle for influence, unclear responsibilities and lack of competencies. In several laws and application decrees since 1999 and in the governmental sector-strategy 2005-2015, the responsibility for the regional rural water supply has shifted from the central state to the *communes*. This transfer is taking place at a very slow pace. Theoretically the *communes* are nowadays entirely responsible for the construction and the management of all water supply infrastructures. In reality the central government and its water agency, however, still play a major role at least in the construction of the infrastructures and in the allocation of funds.

In March 2008 a new decree has come into effect reducing the (obligatory) co-payment of the local population for the construction of the different water supply infrastructure up to 70% depending ion the infrastructure. According to the sector strategy in the departement Borgou 1706 EPE (Equivalent Point d'Eau) would have to be built for the period from 2008 to 2015. Even if these plans succeed, the access to drinking water will not be sustainable unless the water infrastructures will be maintained and managed effectively. Modern rural water supply infrastructures (e.g. water towers, pumps) have to be maintained continuously and thus imply costs which have to be covered somehow by the water users. In the past and until very recently, the water infrastructures have been managed locally by village committees. They have frequently failed to manage and maintain the infrastructures, because they were neither controlled by water agency of the Central state nor did they develop any internal institutions of control (Fig. IV.4.2). Today the majority of the water infrastructure is still managed collectively at the local level. However, this type of local water management has not proven to promote sustainable and long-term water use. Frequently the committees meet obstacles which they can rarely overcome: Conflicts between water users and committees of water management, conflicts between members of these committees, mismanagement of revenues resulting from the sale of water, hesitant repair of breakdowns or malfunctions.

Fig. VI.4.2: Because of mismanagement of the water the photovoltaic cells are out of order and the population has no access to clean drinking water (village Sirarou).

The decentralised *communes* are in charge of the water supply management on the regional level. Since 2009 they can tender the water supply management and the maintenance of the facilities. To assure the management and maintenance of the supply facilities, the *commune* can choose between four types of management and maintenance contracts: (1) direct contract of a contractor by the *commune* (2) triple contract with the user committee and a contractor (3) production contract with a contractor and distribution contract with a user committee (4) contract with a user committee (MMEE 2007: 10).

This flexible system was introduced to improve water supply management and to assure its long term maintenance and sustainability. However, the local population does not really participate in the choice of the water management type and has therefore frequently reservations towards new types of management, because they imply costs which can exclude poor people from clean water supply and force them to use unsafe drinking water. The *communes* do not yet take their role as independent actors in international cooperations. Virtually no cooperation has been initiated by the *communes* with international donors. Despite insufficient financial means and under qualified staff they also lack information such as data bases, maps, statistical data from the national census.

LISUOC (Livelihood Security in the Upper Ouémé Catchment): An information system for the decentralised communes

Many communes do not dispose of statistical data to back potential project proposals for funding. In this perspective, the IMPETUS Information System LISUOC (Livelihood Security in the Upper Ouémé Catchment) has been developed to provide the communes and other actors with relevant data on livelihood security, demographic development and water management. The information system is based on three data sets described below.

Module 1 "Livelihood security and resource use": The quantitative data of this module rely on the IMPETUS survey, conducted in 2004 in Central Benin (see Fig. IV.4.3). Research on vulnerability requires a holistic approach linking the following domains: work, production and resources, capital, health, gift exchange and networks, nutrition, strategies of risk reduction and social organisation.

Data were generated by interviewing men and women separately because social and economic management at the household level are highly individualized. The results provide new perspectives on local risk management in an area of approximately 22,260 square kilometres. This represents approximately one fifth of Benin's total land area. The interviews with 839 women and men were carried out in seven districts (*communes*) of the Departments Donga and Borgou.

The data set has been transformed into an easily manageable tool furnishing analysis results in tabular form or, if desired, as spatial data sets. The parameters can be transferred and stored in any Geographic Information System.

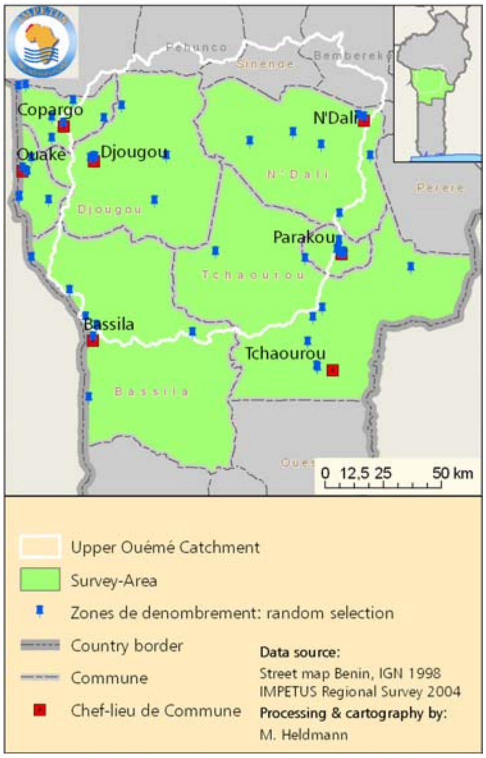

Fig. IV.4.3: Investigation area of the IMPETUS regional survey.

Module 2 "Water management and institutional change": The module "water management and institutional change" is an important tool for *communes* and development projects in the field of water management. It visualises for example the spatial disparities in the distribution of different water infrastructures and thus assists the user in regional planning of water infrastructures. This module is based on a data base of the various water points (water towers, pumps, modern and traditional wells, ponds, water-taps, rivers) of the mentioned seven *communes*. The data base is a compilation of information on the water points collected by the governmental water administration and IMPETUS (through bacteriological and chemical analyses of drinking water).

Module 3 "Demographic projections": The LISUOC module "Demographic projections" is a tool that provides and visualizes information on demographic development in Central Benin. It has been designed to meet the needs of local decision makers and planers, and is based on the IMPETUS population projections that have been calculated on a country wide scale.

The compilation of the demographic projections was carried out with the expert model Spectrum DemProj. Current population figures from the state census in 2002 were used as input data (INSAE 2003). Further important demographic parameters for the *departments* were included such as fertility and death rates as well as migration rates. Assumptions, based on sound regional knowledge, regarding the future development of these parameters were included in the calculation of the projections in yearly stages up until 2025. Projections for population growth and population density include gender and age differentiated population figures. Combining extrapolation and weighing methods the major findings were down-scaled to the lower administrative levels of the *communes* and the *arrondissements* constituting a data base for local planning (Heldmann & Doevenspeck 2008a:103, 2008b: 116).

LISUOC provides demographic data based on one of the central IMPETUS projection, spatially aggregated on the territory of 7 *communes* in Central Benin. Furthermore, present and projected population data from the census in 1992 and 2002 are also included. The data can be visualized either in a table (see Fig. IV.4.4) or in a double-map panel (Fig. IV.4.5) showing the absolute population, the population density or even the age structure of a selected territory.

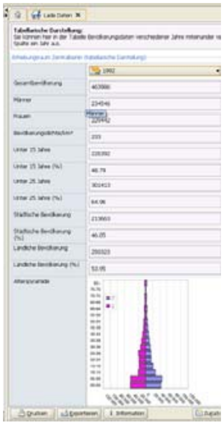

Fig. IV.4.4: Table with Chart from LISUOC Dem.

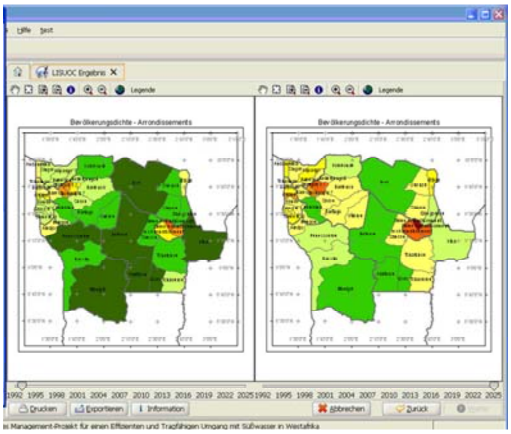

Fig IV.4.5: Double map panel showing population density per arrondissement from LISUOC Dem

The user can easily choose the mode of visualization and switch to another mode. A slide bar with a time-scale below the double-map panel enables the user to visualize the data for different time horizons and to compare current, past and future demographic situations.

Conclusions

In conclusion, the problems of Benin's natural resource management are closely related to processes of new policies, decentralization and democratization. The present analysis of social, political and economic aspects of recent change and their interaction with the environment emphasizes a coexistence of modern and customary land rights, legal pluralism and legal uncertainty. In sum, the decreasing availability of fertile land and water leads to an increase in difficult living conditions.

The highly complex customary land rights and tenure principles prove to be an integral part of the social structure. Customary land rights are implemented by customary authorities and vary from one place to another. At the same time, the national land legislation focuses on land registration as individual property and disregards customary tenure principles. The resulting patchwork of land rights and legal pluralism causes legal uncertainty, contested property claims, tenure insecurity, an uneven distribution of property rights and conflicts over access to land and individualization of land rights. Furthermore, customary strategies for water management, in the absence of a legal framework, interfere with the development of effective policies. On the local level, actors and institutions compete for political power and influence. Informal actors such as traditional authorities gained in influence with the democratization process. At the same time, officials are formally in charge of natural resource management. The agents of different public services, the officials of the local districts and the decentralized communities have been created in the process of decentralization since the 1990s. The communities hold important legal responsibilities, but they have neither the funds nor the competencies to assume those responsibilities.

Rural water supply infrastructures such as pumps have to be maintained by village committees. Frequently, these committees meet obstacles such as conflicts between members and water users, mismanagement of revenues resulting from the sale of water or malfunctions. Recently, the communities have been in charge of water supply management on the regional level. The implemented system is flexible, but the local population does not really participate in the choice of water management types. No cooperation has been initiated by the communities with international donors. Despite insufficient financial means, the communities lack qualified staff and information such as statistical data. Hence, the IMPETUS Information system LISUOC has been developed to provide statistical and qualitative data sets on livelihood strategies, water resources and water management.

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IV.5 Gesundheit / *Health*

Introduction

Water influences public health in different aspects. Rainfall, humidity and water availability determines the survival of vectors transmitting infectious diseases to humans. Therefore changes of these environmental factors alter the likelihood of waterborne human diseases in defined geographic regions.

Malaria is one of the most serious health problems in the world (e.g. De Savingy and Binka 2004) and is causing about 273 million clinical cases and 1.12 million deaths annually. The life-threatening disease is mostly restricted to young children (e.g. Gupta et al. 1999). At least 90% of the malaria attributed deaths occur in sub-Saharan Africa (Greenwood et al. 2005). It is well known that a warm and humid climate triggers diseases such as malaria. This world's most prevalent vector-borne disease is highly sensitive to global warming and associated changes in precipitation (cp. Confalonieri et al. 2007). Water management strategies might be more effectively used to combat malaria in the future. The information system MalaRis ("The impact of climate change on Malaria Risk in Africa"; see http://www.impetus.uni-koeln.de/malaris) assesses the malaria risk under a changed future climate in Africa. It provides detailed data on the distribution, seasonality and variability of malaria transmission. The system further incorporates a rich malaria archive on entomological and parasitological field studies.

Besides changes in the environment water availability is essential for human beings. Drinking water sources can be subject of chemical, microbiological or viral contamination; hence water quality is a major risk factor for public health. The IMPETUS database of drinking water sources (established in 2001, updated 2008) was used to establish the information system SIQeau (Système d´Information Qualité de l´eau). SIQeau enables the user to identify hazardous situations of drinking water supply at village level in the triangle between the cities Parakou, Bassila and Djougou. The system provides background information on drinking water quality, water hygiene and options on the prevention of waterborne diseases and measures in case of emergency. It includes results of bacterial, viral and chemical drinking water analysis. The presentation of this system is followed by an in-depth discussion on the detection of different viral, bacteriologic and chemical contaminants in drinking water sources used in rural areas of Benin.

MalaRis ("The impact of climate change on Malaria Risk in Africa")

<u>Malaria modelling</u>

In order to assess the observed and future occurrence of malaria in Africa, an existing model from the University of Liverpool is used. The so-called Liverpool Malaria Model (LMM) simulates the spread of malaria at a daily resolution using daily mean temperature and 10-day accumulated precipitation (Hoshen and Morse 2004). Various sensitivity experiments reveal that the LMM is fairly sensitive to certain model parameters. The proportion of the population that is carrier of the malaria parasite, the so-called prevalence, strongly depends on the applied mosquito survival scheme. The model uses a malaria recovery rate (r=0.0284) in humans, which results in a maximum level of 65% of malaria prevalence in the model. Furthermore, in areas where temperature is not a factor, the simulated malaria transmission from mosquitoes to humans is mainly governed by the rainfall multiplier. This parameter couples the 10-day accumulated precipitation with the oviposition of female mosquitoes and ultimately determines the size of the mosquito population. At high altitudes, the sporogonic temperature threshold, i.e. the minimum temperature for malaria parasite development in the mosquito, is important. Unlike the LMM model described by Hoshen and Morse (2004), the version used in the present study was parameterised with a different mosquito survival scheme and a sporogonic temperature threshold of 16°C. A modification of the model was needed since the original version does not correctly simulates the spread of the malaria disease (e.g., transmission stops too abruptly in the Sahel).

The seasonality of malaria is projected by means of the MARA Seasonality Model (MSM; MARA: Mapping Malaria Risk in Africa project) that has been developed by Tanser et al. (2003). Different temperature and precipitation criteria are defining the season of malaria transmission. The model is using two monthly and three yearly climate variables.

LMM simulations in West Africa along a north-south transect at about 2°E were based on data from 10 synoptic weather stations that are located in Benin, Niger and Mali. Furthermore, two-dimensional present-day ensemble runs were performed by the LMM on a 0.5° grid for 1960 to 2000. In this case, the LMM was driven by high resolution data from the REgional climate MOdel (REMO), which takes into account land use and land cover (Paeth et al. 2009). In addition, malaria projections were carried out for the period of 2001 to 2050 according to the climate scenarios A1B and B1, as well as land use and cover changes in line with Food and Agriculture Organization (FAO) estimates. The REMO precipitation was corrected relative to Climatic Research Unit (CRU). That was due to the fact that the simulated data differs to observed precipitation data from the 'Institut de Recherche pour le Développement' (IRD).

With regard to the MSM the present-day REMO ensemble runs for 1960 to 2000 were used for the calculation of the present-day climate conditions. The impact of climate change on the malaria seasonality was assessed for the five decades between 2001 and 2050. The "climate" condition of each particular decade was based on three different REMO ensemble runs, which means that they are computed for 30 years.

Present-day malaria simulations

On the basis of the transect station data (1973–2006), the LMM and MSM show a decrease in the malaria prevalence and for the duration of the malaria season from Cotonou at the Guinean coast to Gao in the northern Sahelian zone (not shown). This is not surprising, since mosquito egg deposition is directly proportional to the 10-day rainfall amount. As a result, the size of the mosquito population is clearly associated with the strength of the West African summer monsoon precipitation. At the most northern transect stations in Tillabéry (14°12'N, 1°27'E) the malaria season lasts only several weeks and in Gao (16°16'N, 0°03'W) the disease occurs epidemically.

The decline of the malaria prevalence towards the Sahara is also shown by the two-dimensional LMM ensemble simulations. In agreement with the annual precipitation amounts, the simulations of the LMM (MSM) show a decrease in the malaria prevalence (length of the malaria season) from the Guinea Coast towards the Sahel for the period 1960 to 2000 (Fig. IV.5.1a and 2a-c). Malaria transmission is year-round in the equatorial tropics in the area of the largest precipitation amounts, e.g. in southern Cameroon, Gabon, Congo, and Uganda. The regions of epidemic malaria occurrence are defined by a large inter-annual variability of the annual malaria prevalence maximum. Such areas are located in the Sahelian zone between 13 and 18°N as well as in highland areas in East Africa (Fig. IV.5.1b). South of the Sahel and outside of the East African Highlands the malaria spread in the simulated population is more stable from year to year and is thus classified as endemic.

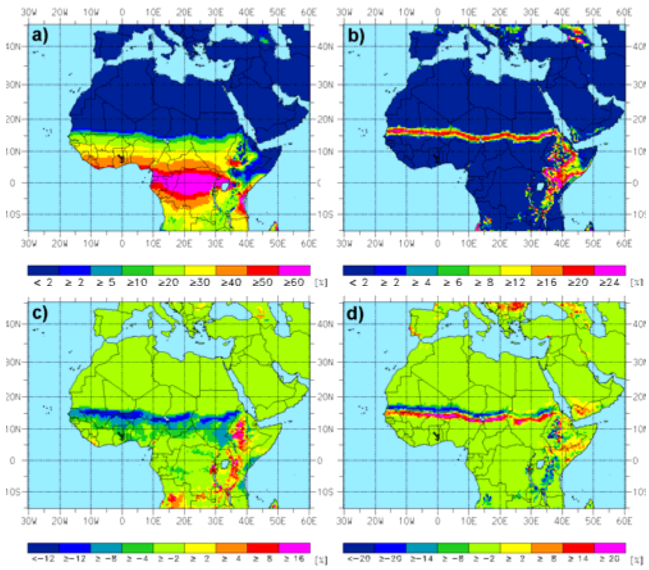

Fig. IV.5.1: LMM ensemble simulations of: (a) Annual averaged prevalence (in %) and (b) standard deviation regarding the annual maximum of the model prevalence (in %) for 1960 to 2000. (c) and (d) same as (a) and (b) but here for the differences (in %) between the last decade of the A1B scenario (2041–2050) and the period 1960 to 2000.

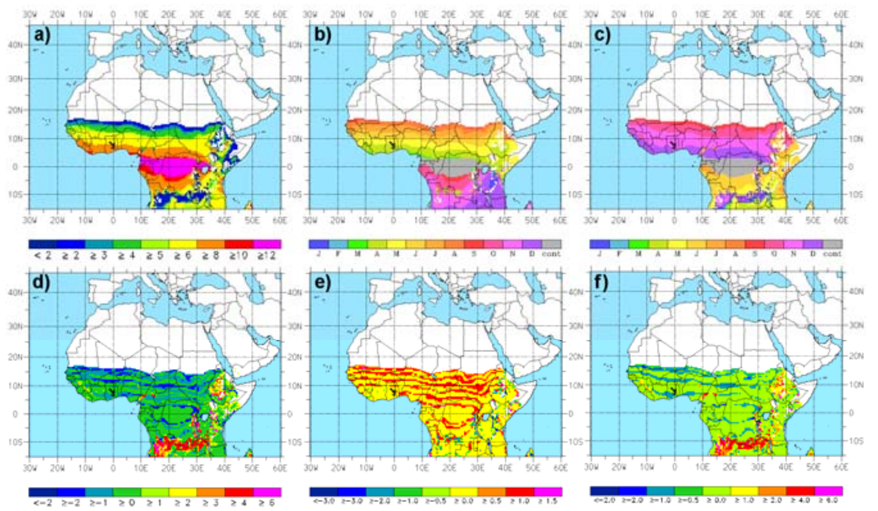

Fig. IV.5.2: MSM simulations of (a) length (in months), (b) onset, and (c) end of the malaria season for 1960 to 2000. (d), (e), and (f) same as (a), (b), and (c), but here for the differences (in months) between the last decade of the A1B scenario (2041–2050) and the period 1960 to 2000.

The presence of highlands in East Africa is causing a more complex pattern in the distribution of the malaria season length. Parts of Ethiopia, Kenya, Tanzania, Rwanda and Burundi are covered by highlands and are therefore characterized by lower temperatures than nearby plain areas. Those are the reason for short malaria seasons or even the lack of malaria seasonality in the East African highlands. By contrast the lack of a malaria season around the Horn of Africa is due to low annual precipitation amounts (Fig. IV.5.2a-c).

Malaria projections (2001-2050)

Largely due to the land surface degradation, REMO simulates a prominent surface heating and a significant reduction in the annual rainfall amount over most of tropical Africa in both scenarios (Paeth et al. 2009). As a consequence, the malaria projections show a decreased spread of the malaria disease in the Sahelian and Sudanian zone for the decade 2041 to 2050 (Fig. IV.5.1c). In addition, the year-to-year variations of the seasonal maximum of malaria prevalence are reduced in the northern part of the Sahel. Therefore, for these areas fewer epidemics or even a malaria retreat from some regions might be expected. However, variability is increasing in the southern part of the Sahelian zone (between 13 and 16°N). As a result, epidemics in these more densely populated areas are becoming more likely as parts of the population will lose their partial immunity against malaria. The maximum of malaria transmission farther south, for example in Benin, remains stable (Fig. IV.5.1d). However, due to a drier and shorter rainy season the malaria transmission period will be shorter (Fig. IV.5.2d-f).

By contrast due to higher temperatures and nearly unchanged precipitation amounts the malaria prevalence increases in East Africa, in particular in highland areas. According to the period 1960 to 2000 the standard deviation of the annual maximum prevalence is also high in the East African Highlands. In East Africa the change of the malaria transmission is not as clear as in West Africa. Here areas where malaria transmission is becoming more stable or instable are side by side. Highland areas that were formerly unsuitable for malaria are becoming suitable in a warmer future climate and epidemics are becoming more frequent. In some other areas transmission is increased and people will improve their partial immunity against malaria.

Additionally, higher temperatures and unchanged or even increased precipitation amounts cause an increase of malaria transmission in the central area of Angola and northern parts of Zambia. According to the MSM simulation the malaria season last up to six months longer in the last decade of the A1B scenario (2041-2050) than in the period 1960 to 2000. Also a malaria prevalence increase is expected by the LMM simulations. The year-to-year variability of the malaria decreases and malaria is therefore expected to become more stable. The results of the LMM ensemble runs for scenarios A1B and B1 are similar. However, changes are generally stronger in scenario A1B than in B1 and the amplitude of change is most pronounced at the end of the simulation period in the 2040s.

LMM simulations have so far only compared with malaria distribution maps from the MARA project. A more detailed validation of LMM is needed and will be based on entomological and parasitological data from West African field studies. By means of the validation shortcomings of the LMM might be detected. In such a case the parameter setting of the model will be changed and finally more resilient LMM simulations will increase the confidence of the assessment of malaria risk in Africa.

Analysis of drinking water quality and SIQeau ("Système d´Information Qualité de l´eau")

Water quality monitoring

Several chemical, viral, bacteriological and parasitical contaminants of drinking water sources can be a danger to the consumers. Since the Impetus Laboratory of Water Analysis was built up in Parakou and started its work in 2002, methods for the detection of viral, bacteriologic and chemical parameters have been established and applied to investigate the water quality of the rural Upper Ouémé catchment. Furthermore, drinking water sources in the Upper Ouémé catchment were located, documented, classified, and registered (Fig. IV.5.3). This database of approximate 1900 water sources serving as supplies in 105 villages is used to coordinate sample collections in different seasonal settings and to plan further interventions. Due to drying up of wells and construction of new water supplies, the exact amount of water sources varies within the course of the year. The total number of water supplies increased over the intervening years: from ~ 1300 in 2002 to ~1900 in 2008.

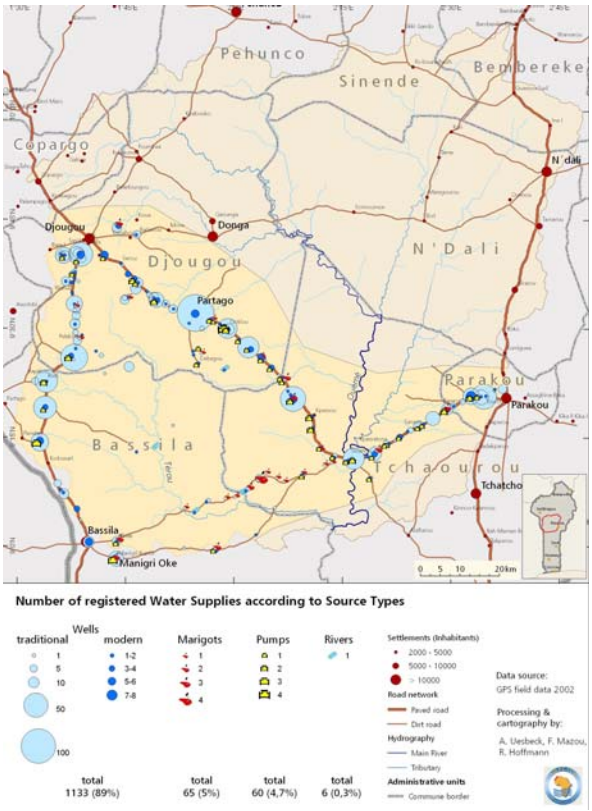

Fig. IV.5.3: Drinking water sources in the triangle Parakou-Bassila-Djougou.

In the triangle between the cities of Parakou, Bassila and Djougou traditional and modern wells are mainly disposable for the villagers as water supply: they constitute 90 % of all water sources. Closed pump systems represent only 5% of all water supplies in the Upper Ouémé catchment. Even though several new pumps have been constructed since 2002, the proportion of the different types of water supplies has remained the same. In several villages the inhabitants still do not have access to ground water from boreholes at all.

To address the frequency and pattern of viral contamination, samples from drinking water sources in the Upper Ouémé catchment have been taken during the dry and wet season. These water samples were analysed for the presence of adenoviruses (gastrointestinal as well as respiratory types) as indicator for viral/faecal contamination and rotaviruses as important pathogen in developing countries of severe diarrhoea especially in small children. Ten litres of water each were collected, transported to the IMPETUS Laboratory and passed through two 1MDS cartridge filters (CUNO filter system, ZetaPlusRVirosorbR, 3M Germany) with a flow rate of 5 l/h. The real-time PCRs for Adenoviruses and Rotaviruses were carried out on a Light Cycler (Roche) in Cologne.

Pathogen bacteria causing waterborne diseases as *E. coli*, *Vibrio cholerae*, *Shigella ssp.*, *Yersinia ssp.* or *Salmonella ssp.* have been isolated from water samples after inoculation of appropriate enrichment broths and growth on selective nutrient agar plates. For identification of the organisms, the biochemical properties of suspicious colonies have been determined and finally being confirmed at the institute of Medical Microbiology, Immunology and Hygiene in Cologne.

Physico-chemical parameters as the pH, water temperature and water conductivity have been analyzed directly while water sampling in the field with a portable pH/conductimeter.

Viral, Bacteriological and parasitological water quality in drinking water sources

Adenoviruses or rotaviruses were found in 13% of all drinking water sources , of which adenoviruses clearly dominated (Verheyen et al. 2009). The dominant detection of adenoviruses might be explained by the great variety of human diseases caused by adnenoviruses leading to frequent deposition of this virus in the environment. Different Adenovirus Types responsible for respiratory infections were often found in stool samples together with viruses typically causing diarrheic diseases in stool samples from children under the age of five hospitalized in Parakou University hospital. Therefore adenoviruses might also be an appropriate candidate as indicator system for viral contamination in environmental samples (Godfrey et al. 2005, Jiang et al. 2001). Overall, latrines within a 50m-radius of the testing sites were a significant risk factor for viral contamination of pumps and wells (Verheyen et al. 2009). This distance is in concordance with findings during an outbreak of hepatitis-A conferred by a leaking sewage tank 60m apart from water wells (De Serres et al. 1999). It was even speculated that viruses can travel distances greater than 1000m under optimized conditions (Huang et al. 2000). The increasing socioeconomic properties in the analysed rural area led to an increase of latrines, which decreased the risk of human infections by avoiding direct contact with faeces. But on the other hand, the increase also contributed to the potential viral contamination of surrounding drinking water sources nearer than 50 m to the latrines.

Continuous bacteriological drinking water analyses revealed that 70% of all drinking water supplies in the rural Upper Ouémé catchment were contaminated with *Escherichia coli (E. coli)*. *E.*

coli lives in the intestinal tracts of humans and other animals and is the principal indicator of fecal pollution of water. While this organism is generally harmless to human, it does live under the same conditions that human pathogens live. Disease-causing organisms can be carried in fecal-contamination and the detection of *E. coli* in fresh water indicates that pathogens such as *Shigella* spp., and *Salmonella* spp. may be present as well.

Enteric Salmonellae (*S. enterica* subspecies *enterica*) have been isolated from more than 8% of the water sources that are *at the disposal for of* villagers. Determination of the antigen formula of these strains revealed that they belong to a great variety of different serotypes rarely causing Salmonellosis in European countries. The primary basis for classification of the pathogenic bacterium *S. enterica* is the serotyping scheme of Kauffmann and White in which about 2500 serovars have been recognized according to their flagellin (H-) and lipopolysaccharide (O-) antigens. Two new serotypes of salmonella were detected -Salmonella Parakou from a water hole, and Salmonella Kaki Koka from a stool sample-, and were variefied by the WHO reference laboratory for *Salmonella* in Paris.

The results of viral and bacteriologic analysis reveal that water from modern and traditional wells that are used as drinking water supplies in most cases do not provide potable water. Very precarious hygienic situation can be observed in most villages. Free running animals, the lack of basic sanitation, uncovered water supplies and plastic buckets for scooping water that are not stored properly after use may provoke of fecal contamination of drinking water.

Photometric analysis revealed that water samples from about 10% of the pumps in the Upper Ouémé catchment are contaminated with nitrates (> 50 mg/L). Drinking water high in nitrate is potentially harmful to infants under six months of age and can provoke methemoglobinemia, commonly called "blue baby syndrome". Proximity to latrines was also found to be one reason of nitrate contaminations of water from boreholes. These findings indicate that different aspects have to be considered to improve drinking water quality in rural areas of Africa without general water supply.

Microbiological water quality was much better in pumps than in modern or traditional wells. With very few exceptions - *in cases of so called “pompe Vergnet”* - water from boreholes with closed pumping systems did not provide contamination by faecal bacteria. But viral contamination of 8% of investigated pumps indicates *different levels of water quality*.

Information System SIQeau

The Information System SIQeau has been developed *on the basis of the insights into* the situation of drinking water quality and the database providing information of almost all water supplies in the triangle Parakou-Bassila-Djougou, which was updated in 2008. This database has been enlarged by the LISUOC/DGEau database, so that finally SIQeau contains information of water supplies of *all seven* communes (Parakou, Bassila, Djougou, N´dali, Tchaourou, Ouaké, Copargo) belonging to the Upper Ouémé catchment.

SIQeau contains basic information about all different aspects of drinking water quality and factors endangering water consumers, results of water analysis can be requested and the system highlights hazardous situations at village level. The user can inform himself about options for action to ameliorate the situation of drinking water in a certain area. Options like building new pumps, sanitation of old village wells, disinfection of contaminated water supply or alternative systems for storage of water in rural households have been developed on the basis of research results concerning water quality.

SIQeau also provides information about first aid steps and a contact database of responsible persons that should be informed and consulted in case of an outbreak of water borne infectious diseases. For each village SIQeau determines the persons in charge and the corresponding contact data. The user can observe the situation of drinking water supply and quality in a certain village or area, by choosing several attributes as the types of drinking water source, the contamination and the depth of the wells. As water supplies from all communes belonging to the Upper Ouémé region have been integrated into the system, the situation in a chosen village or area can be displayed in a GIS-map. A hygiene buffer around latrines can be activated to indicate endangerment for sources that have a close proximity to latrines.

SIQeau serves as monitoring tool, as data for new water sources can be submitted by the user and those from old water sources that are out of order can be modified or deleted from the database. GPS-data and photos can be inserted as well as descriptions of the water sources and results of water analysis. The contact-database can also be modified in case of changing responsibilities dealing with water quality and infectious diseases.

The continuous updating of all used SIQeau-versions shall be observed and delegated by one person in charge of the system, who regularly visits all communes and other users of the database to unify new data and modifications. This person can also be consulted in case of operating difficulties or loss of data.

Conclusions

Climate change affects the living and working conditions of humans and also the likelihood of specific diseases. Public health systems in developing countries are already challenged by the burden of diseases caused by infectious microorganisms. Changes in temperature or rainfall alter the distribution of vectors and the prevalence of diseases. Models like the LMM can help to estimate the burden of the disease in the future with respect to environmental changes. Furthermore, the modeling of different scenarios helps to predict effects under different conditions. Using these results, challenges for public health systems can be standardized and preparations can be planned. It is in the nature of information systems that they are less useful for the far future but help to provide reliable data in a current situation and help to plan interventions in the near future. Additionally, in the IMPETUS laboratory in Parakou, different methods to monitor water quality have been set up and are now applicable by trained persons. A major impact of the IMPETUS project is that water quality can be addressed in more detail in Parakou and surrounding areas. Overall, different data sets were implemented that can help to improve the public health system in these areas.

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V. Themenbereiche in Südmarokko / *Southern Morocco and its Subject Areas*

Coping with the impacts of Global Change is a major challenge for the vulnerable semi-arid to arid Drâa catchment, as well as for Southern Morocco as a whole, because of its already dry conditions and limited water availability. People rely on water not only for drinking, but also to secure their livelihood by irrigation for subsistence or cash crop farming, live stock production, small enterprises, and tourism. Other environmental issues pertinent to the area include land degradation by overgrazing, soil and water salinization due to intensive irrigation agriculture and depletion of the groundwater reservoirs by overuse of groundwater for irrigation purposes. This chapter highlights examples of the ways in which Global Change may affect the future of the Drâa catchment.

In Chapter V.1 the importance of proper resource (both water and land) management is tackled as it relates to livelihood security. The main income-generating activities in the region are agriculture, which is heavily dependent on water availability, and livestock husbandry, which relies on land and vegetation productivity. Agronomic and economic options for irrigation water management are analyzed and simulated for the IMPETUS climate scenarios with a hydro-economic simulation model. Special emphasis is given to the development of farm income, taking into account water scarcity, groundwater overuse and irrigation-induced salinization of soil and water. Examples of intervention possibilities, like the implementation of groundwater charges, clearly show how policy might be able to cope with the effects of Climate Change. A sound analysis of the resource management strategies for the rangeland demonstrates the capability of the transhumant pastoralists to cope with the existing variability of fodder resources on local pastures. Simulations of the vegetation dynamics in relation to grazing activities with an ecological model for climate scenarios help to illustrate the resilience of the vegetation to grazing impacts.

The focus of Chapter V.2 is the availability of water in the Drâa catchment in the future scenarios. Using a number of adapted, calibrated and validated models transferred in management tools, a general decline in surface water availability, but no particular trend for extreme periods with scenario calculations is demonstrated. Snow coverage in the High Atlas will decrease in the future due to an increase in air temperature. The analyses, therefore, show a likely decrease in surface runoff in the Upper Drâa valley. Reduced surface water availability will increase the pressure on the groundwater resources downstream of the reservoir Mansour Eddahbi, as demand for irrigation water is high. Both climate and socio-economic scenarios reveal significant effects on water resources. Due to limited freshwater from the reservoir, soil and groundwater salinity will increase in the future, eventually causing the failure of food production if no appropriate measures are undertaken. Furthermore, Klose et al. highlight the problematic of the different downscaling methodologies for the various regional climate model outputs.

In Chapter V.3 land use management options in the High Atlas region are described under the impact of extreme climate events. Emphasis is given to pastoral land, where key traits were identified, that mitigate the negative effects of extreme weather events (droughts and floods). The authors demonstrate that local land use mitigates drought effects through preventive natural resource management, such as herd management, and access to alternative resources. This adaptive land management ensures the availability as well as the resilience of pastoral land and increases the capacity of rangeland vegetation to buffer rainfall variability. Using a soil erosion model, the current and future risk for soil erosion by water is assessed. Climate scenario calculations show that accelerated erosion will occur due to a reduced protective vegetation cover and higher rainfall variability. Depending on the combination of different climate and socio-economic scenarios, the negative effect could become either more or less severe.

In the last Chapter (V.4) an overview of local social structures are provided that govern processes of decision making related to natural resource management in southern Morocco. Focus is given to processes of socio-economic and demographic change in the Drâa catchment directly influenced by water availability on both the regional and local scales. In this context, patterns of migration, as well as ethnic affiliations, social status of individuals or groups and their effects on economic strategies, are analyzed. Labor migration is a common strategy to locally secure livelihoods of the rural population, leading to relatively low population growth in the rural areas and increasing urbanization.

V.1 Existenzsicherung / *Livelihood Security*

Introduction

The arid zone of the Drâa Valley is characterized by scarcity and heterogeneity of water supply, which strongly limits income created by agriculture. Agricultural production is a major activity in the desert oases, both for food security and income supplementation. Rangeland areas are used by both sessile and nomadic pastoralists, whereas arable and irrigated (traditional) agriculture is concentrated in the oases. The anticipated climate change may lead to a further shortage of water in the region. Both traditional and modern approaches to resource management are thus faced with the challenge to secure the income of a growing population while using land and distributing water resources without compromising the natural resource base. Within the problem cluster "livelihood security" we thus focussed on income-generating activities strongly related to water availability and land resources.

Crop management in oasis agriculture in the Drâa basin

In the South of Morocco, crop production is based on irrigation in oasis systems. Two different types of oasis agriculture can be distinguished: (1) The mountain oases with virtually permanent supply of high quality surface water, but lower mean temperatures and predominantly skeleton - rich soils and (2) the desert oases with limited and controlled supply of high quality surface water from the "Mansour Eddahbi" dam, complimented by ground water with declining quality towards the southern oases. Water scarcity is the principal problem in years of drought and/or insufficient level in the Mansour Eddahbi reservoir. Farmers thus have to amend with more costly groundwater, which has variable salt contents leading to salinity over time resulting in decreasing crop yields.

Date palms are the economically the most important crop, while the dominant annual crop is wheat, covering 58 to 74 % of the cultivated area (see Fig. V.1.1), alfalfa and barley ranking second. All other crops have less than 10 % coverage with exception of the oasis Ternata, where vegetables are produced on slightly over 10 % of the acreage.

The production of dates is carried out usually on border lines of irrigation channels and irrigated fields. Transpiration measurements show that date palms in the oases consume about 700 mm of water per year (Gresens 2006) corresponding to around 0.094 kg dates m^{-3}. *Artemisia* shrubs in contrast transpire on the average 12 mm per year. Hence the water consumption of one hectare of date palms equals roughly 60 ha of natural vegetation (IMPETUS 2006). Drought stress reduces transpiration by 60 to 70 % in both species, but leads to an increased mortality of date palms. Natural vegetation, however, reacts by reducing the individual biomass, still maintaining population density (IMPETUS 2006).

Wheat yields may reach 5 to 6 Mg $ha^{-1} \cdot a^{-1}$ under optimum water and nutrient supply. The crop is, however, more sensitive to salinity above 4 dS m^{-1}, becoming the major yield limiting factor in the Southern oases. Field experiments at the research station of ORMVAO at Zagora indicate that wheat yields of almost 4 Mg $ha^{-1} \cdot a^{-1}$ can be achieved with 4 applications of 70 mm with optimal timing at panicle appearance and the end of flowering. Water use efficiency of wheat production has been calculated to range between 0.71 to 0.85 kg wheat m^{-3}. Nevertheless, harvest indices between 0.18 and 0.28 are indicative for further constraints (heat stress, sub-optimal/unbalanced nutrient supply).

In a farm survey with 81 farms combined NPK (14/23/11) and $(NH4)_2SO_4$ mineral fertilizer application at 600 and 1000 kg $ha^{-1} \cdot a^{-1}$ almost tripled wheat yields compared to 17 to 100 kg $ha^{-1} \cdot a^{-1}$. Yield varies considerably, though, due to constraints of water supply (Gresens 2006).

Due to lower temperatures and shorter vegetation periods in the mountain oases there is only one crop per season above 2500 m. At lower altitudes, two crops per year are feasible, usually barley as dominant annual crop followed by maize and vegetables.

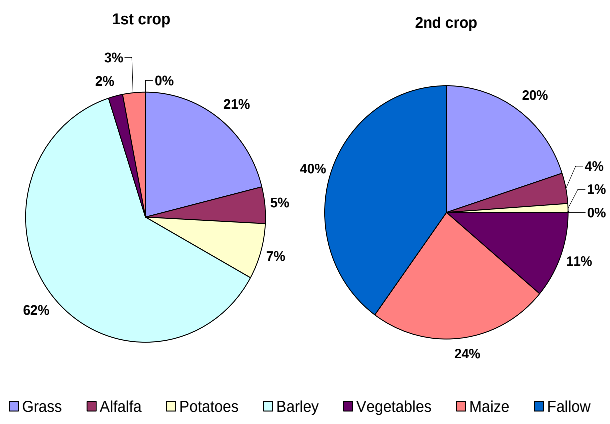

Fig. V.1.1: Percentage of main crops during the first and second cultivation cycle at Tichki (2300 m asl).

Due to the abundance of water at these sites, irrigation of up to 2300 mm per crop and year is used (IMPETUS 2006). When related to the yields of barley (30 to 60 dt ha-1·a-1) and maize (8 to 30 dt ha-1·a-1), the calculated water use efficiency (WUE) is in the range of 0.17 to 0.12 kg m-3. This is roughly a fifth of the WUE of wheat measured in the Middle Drâa valley, where a maximum of 420 mm is been applied per crop. Obviously, the farmers in the mountain oases apply water excessively which thus drains off unproductively.

Assessment of economic effects of climate change in the Middle Drâa oases using the MIVAD model

We assessed the impact of climate change and changing water availability on water use for irrigation and farm income of the rural population in the six Drâa oases. Applications of the MIVAD model – described in more detail in chapter 7.2.2 of this report – for recursive-dynamic simulations are briefly outlined. Examples are presented for assessing the impact of climate change and intervention options.

To simulate the impact of climate change on water use, the MIVAD model is modified to include the climate change scenarios B1 and A1B of the IMPETUS IPCC scenarios. Recursive-dynamic simulations with MIVAD are carried out for the years 2000-2020 in accordance with the national development strategy of Morocco. Simulations include aspects of population growth, resulting in an increasing demand for drinking water in the Drâa Valley at a rate of 3.1 %·a-1 for urban and 0.8 %·a-1 for rural areas (based on results of Penitsch et al., 2005). Water releases from the reservoir into the Middle Drâa river basin are decided upon an annual basis.

Climate change scenarios were introduced into the MIVAD model by transforming the rainfall of the IPCC scenarios into scenarios of inflows into the Mansour Eddahbi reservoir by regression analysis (rainfall data and inflows are highly correlated: Schulz et al 2008). Both, the record of historical inflows since 1972 until 2000 as well as the estimated inflow scenarios in Fig. V.1.2 suggest that inflows are likely to decrease in the future. Standard deviations are calculated from climate change scenarios for three ensemble runs for the scenarios of A1B and B1. It can be stated that inflows are likely to decrease, although this interpretation has to be considered cautiously as variation is high between ensemble runs.

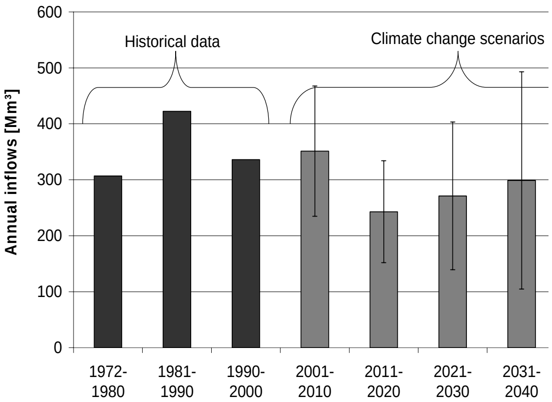

Fig. V.1.2: Historical and projected inflows-for the Mansour Edhhabi dam (plus S_d from ensemble runs).

The inflows into the Mansour Eddahbi reservoir are an exogenous variable in the MIVAD model and constitute a decisive factor for the model results as they determine the major part of the water availability in the system. Lateral inflows and groundwater aquifers also contribute to water availability, but as most groundwater is extracted from the shallow aquifers below the river bed, groundwater availability is directly dependent on the amount of reservoir inflows due to infiltration of water from the river bed and infiltration from irrigation water on the fields (compare also groundwater balance as described in Chapter V.2).

Impact of climate change on modelling results

Alternative water distribution is discussed as an intervention scenario, and water pricing as one option for groundwater resource preservation was examined in the model runs. Fig. V.1.3 summarizes the impact of climate change until 2020 on water use and farm income, where the latter is likely to decline due to lower water availability. This is reflected, too, by the agricultural surface water use drawn from the Drâa River for irrigation. Consequently, groundwater use is likely to increase nearly twofold, depending on the underlying climate change scenario (being lowest with scenario A1B).

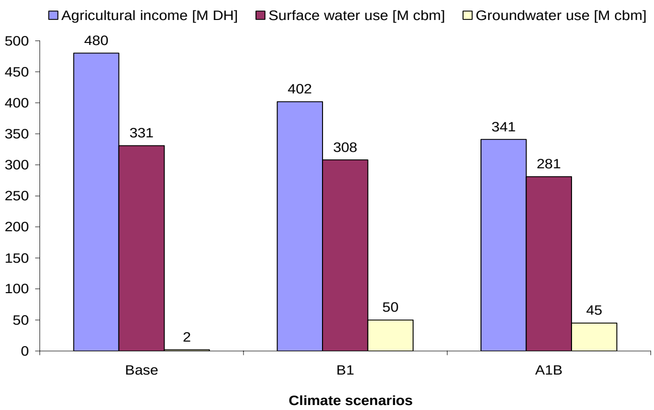

Fig. V.1.3: Development of agricultural income, surface (SW) and groundwater (GW) use: comparison of base line (averages from 1972 until 2000) to B1 and A1B scenarios (calculated from 2000 to 2020). Source: calculation with the MIVAD model in 2009. Results of the climate change scenarios represent one ensemble run for each scenario (912 and 922) from 2000 until 2020. The base scenario refers to an average of inflows from 1972 until 2000.

Results in Fig. V.1.3 emphasize the importance of water management measures to assure a more sustainable water use in the future. Two intervention possibilities shall be discussed here. In the first, simulations are made for an alternative water distribution strategy of the surface water that is provided by reservoir releases through the Drâa River. In the second simulation, groundwater pricing is discussed as one option for groundwater resources preservation.

Currently, water is distributed quite evenly among the six oases. In the MIVAD model this is represented by a share of surface water to each oasis depending on the amount of arable land of this oasis and its water requirements depending on the kind of crops cultivated. This is represented by the 'area distribution' in Tab. V.1.1.

Table V.1.1: Agricultural income under alternative water distribution rules (in Million Moroccan Dirham) in the six oases (A1 to A6). Source: MIVAD model simulations 2009. Note: The scenario assumed is the A1B climate change scenario (run 912) of the IMPETUS project which has been transformed into reservoir inflows.

	area distribution	*Optimal*
Mezguita (A1)	47.3	51.4
Tinzouline (A2)	54.8	57.3
Ternata (A3)	96.9	102.0
Fezouata (A4)	47.5	50.0
Ktaoua (A5)	68.3	70.2
Mhamid (A6)	26.6	28.9
Average	56.9	60.0
Standard deviation	23.8	24.6

If no explicit water distribution rule is applied to water allocation among oases, MIVAD allocates surface water according to the principle of maximization of basin-wide income, which is why this form of water distribution is called 'optimal' water distribution. Applying area-based water distribution rules leads to a more even distribution of water and farm incomes among the oases as compared to 'optimal' distribution.

Another option is the implementation of groundwater charges to stabilize groundwater use. The problem of water pricing in other river basins in Morocco has been discussed by Tsur et al. (2004), who states that water is charged in all other river basin of Morocco, but charges often do not cover the cost of operation and maintenance of the irrigation schemes. Heidecke et al. (2008) conclude for the Middle Drâa basin that groundwater pricing is a favourable option in long periods of drought as groundwater is preserved until surface water is scarce. However, this analysis did not include aspects of groundwater salinity and climate change. Thus, in the following simulations a groundwater charge and its impact on groundwater tables and farm income evaluated under the assumptions of climate change scenario A1B. Fig. V.1.4 shows the fill levels of the aquifers. In the simulations with no charge groundwater use is still more expensive than surface water due to running costs of the motor pumps. Nevertheless, with an additional charge of 40 Moroccan cents, groundwater use becomes even less attractive than surface water and only used for irrigation if surface water is scarce and groundwater use is economically efficient. Consequently, farmers use less groundwater for irrigation and groundwater levels remain more stable over years.

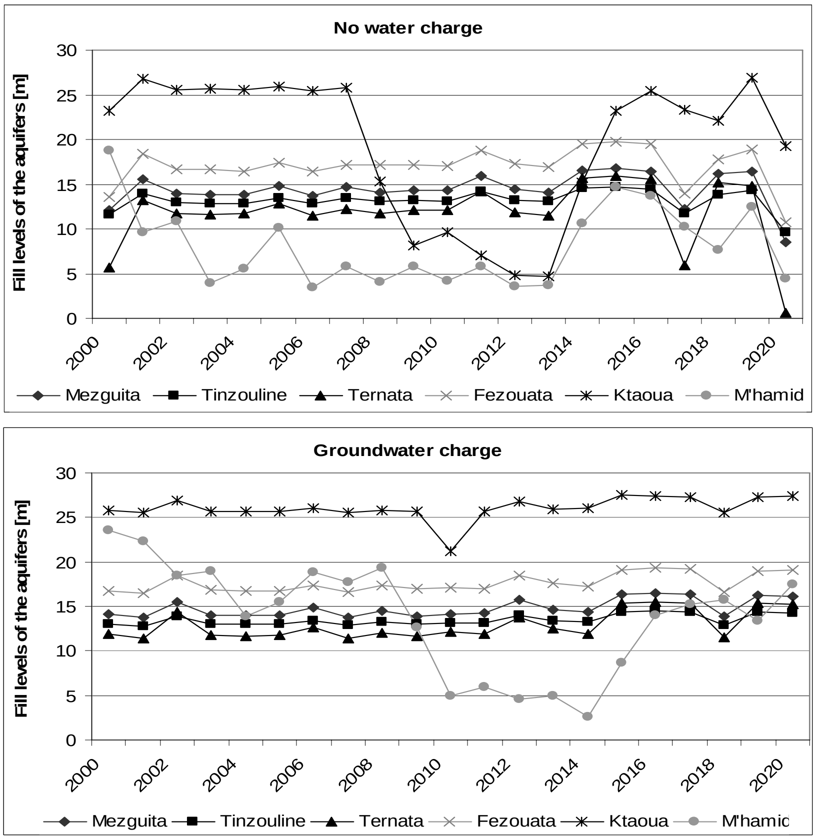

Fig. V.1.4: Fill levels of the six aquifers (GW1 to GW6) of the six oases in the Middle Drâa valley (Depth of water table in meter [m]). Source: MIVAD model simulations 2009. Note: The scenario assumed is the A1B climate change scenario (run 912) of the IMPETUS project which has been transformed into reservoir inflows.

This has a direct effect on farm income in the six oases along the Drâa River (not shown). It was found that in the long run a groundwater charge leads to more constant farm incomes.

The effect of a groundwater charge on groundwater use and income is summarized in Tab. V.1.2. The implementation of a groundwater charge leads to less groundwater use as the average over 20 years. Surprisingly agricultural income is also slightly higher than with no extra charge although the farmers have extra costs for using water for irrigation. This is due to more constant groundwater availability over 20 years, thus stabilizing farm income as well. This is also reflected by the lower shadow price for irrigation water.

Table V.1.2: Impact of a groundwater charge in contrast to no charges (average of 20 years assuming climate change scenario A1B). Source: MIVAD model simulations 2009

	No charge	**Groundwater charge**
Agricultural river water use (Mm^3)	280.50	303.70
Agricultural groundwater use (Mm^3)	44.60	25.60
Agricultural income basin-wide (M DH)	341.40	351.30
Shadow agricultural water price (DH/m^3)	1.79	1.76

Pastoralist's resource management and livelihood security in the Drâa region - example Ait Toumert

Transhumant livestock husbandry is the second important resource-based production which rests on the vast rangelands in the region. Strategies of pastoral range management are classified (Fernandez-Gimenez and Le Febre 2006) into: Mobility to access natural resources in different localities or regions on an intraseasonal and interseasonal level (Adriansen 2005; Dwyer and Istomin 2008), differentiated into larger scale movements between pastures (macro-mobility) and movements around waterholes and temporal settlements (micro-mobility) (Niamir-Fuller 1998). Diversity refers to the variation of vegetation types exploited by pastoralists, flexibility to socio-economic strategies coping with environmental variability (such as herd diversification, sale/slaughter of livestock, alternative monetary income). Reciprocity refers to social networks (informal insurance: McAllister et al. 2006b). Reserve mechanisms are ecological or economic buffers for times of resource limitation (Frank et al. 2006), such as pastures that are spared (Retzer et al. 2006; Müller et al. 2007), or monetary income from other sources.

Tab. II-5.1-3 summarizes important socio-economic parameters of the three types of Ait Toumert households as related to livelihood security - the richer and larger a household, the higher the number of livestock per capita. Alternative income from wage labour contributes about a fifth of total income for household types "B" and "C".

Table V.1.3: Socio-economic parameters in three Ait Toumert households types representing different pastoral livelihood schemes

Socio-economic parameter	Variables	Type A: poor	Type B: average	Type C: rich
Family structure	De jure members	7	9	24
Alternative income sources	Income from wage labour	none	22 %	21 %
	Financial support per year and person	none	2,750 DH/a	1,600 DH/a
	Gardening (Agriculture)	no	No	yes
Livestock resources	Herd size / de jure member	21	39	50
	Satisfaction with herd size	satisfied	+ 143 %	+ 267 %

Strategies to overcome shortages, e.g. feed supplementation, truck transport, selling a large stock of animals, are selected according to the household's wealth. Mobility is reduced to micro-mobility usually during good and very bad years with additional feed supply. It has become a common practice irrespective of year. Feed/forage supplementation, introduced by the government during drought spells in the 1980s, has thus become a routine practice. All management strategies aim at minimizing livestock mortality. Household C type maintained a constant herd size even under drought. In contrast, substantial losses of animals were reported by households of type B (approx. 80%), and C (60 %). After severe drought, "B" could restock his livestock faster than Type A. Socio-economic resources and individual networks as economic buffers become increasingly important (Tab. V.1.4). Ait Toumert herdsmen are using all five classes of management options, including reciprocity by grazing agreements with neighbouring groups (Tab. V.1.5).

Typical of recent changes in pastoral societies (Bollig 2006; Moritz 2008), modern strategies adopted in the past decades have lead to a diversification, the number of specific and principal strategies have increased. While wealthy households are highly diversified and make full use of modern strategies, the livelihood security of poorer households depends more on traditional resource management (see as well Barrett et al. 2001), in any case seeking or creating reliability by buffering resource variation (Roe et al. 1998). However, a diversification of management strategies may increase the system's vulnerability to collapse when households increasingly rely on economic instead ecological buffers (Frank et al. 2006), partially uncoupling society from environment. This may lead to an overall decrease of a pastoral system's resilience due to a weakening of environmental feedback (McAllister et al. 2006a).

Table V.1.4: Management strategies of three Ait Toumert households related to their socio-economic framework and the availability of natural fodder resources of a particular year.

Type of year	**Herd management strategies**	**Management strategies as used by household type***		
		Type A: poor	**Type B: average**	**Type C: rich**
Good year	Full transhumance cycle	-	Yes	Yes
	Reduced mobility	-	-	-
	Feed supplementation	**Yes**	**Yes**	**Yes**
	Truck transport	-	-	-
	Mass selling of animals	-	-	-
Average year	Full transhumance cycle	-	Yes	Yes
	Reduced mobility	**Yes**	**Yes**	-
	Feed supplementation	**Yes**	**Yes**	**Yes**
	Truck transport	-	-	-
	Mass selling of animals	-	-	-
Bad year	Full transhumance cycle	-	Yes	-
	Reduced mobility	**Yes**	**Yes**	-
	Feed supplementation	**Yes**	**Yes**	**Yes**
	Truck transport	-	-	**Yes**
	Mass selling of animals	-	-	-
Very bad year (drought year)	Full transhumance cycle	-	-	-
	Reduced mobility	**Yes**	-	-
	Feed supplementation	**Yes**	**Yes**	**Yes**
	Truck transport	-	**Yes**	**Yes**
	Mass selling of animals	-	**Yes**	-

Table V.1.5: Principal management strategies used by pastoral nomads, and specific strategies of Ait Toumert herdsmen.

Principal strategy	**Specific strategies of the Ait Toumert***
Mobility	Macro-mobility (transhumance); reduced mobility; **truck transport**
Diversity	Diversification of livestock (goats, sheep); transhumance; **truck transport**
Flexibility	**Mass selling of animals; alternative monetary income**
Reserve	Temporal resting of pastures via the *agdal* institution (see chapter 6.3); **feed supplementation**
Reciprocity	Reciprocal grazing agreements for winter pastures; **reciprocal acceptance of 'grazing tourism" via truck transport**

*Modern strategies which have evolved during the past decades are shown in bold.

Modelling vegetation dynamics as related to pastoralist's grazing activities in the Drâa basin rangelands

Grazing intensities affect both, the spatio-temporal vegetation composition and the hydrological cycle in rangelands. Maintaining high stocking rates as a strategy to offset climate variability is leading to an enhanced degradation of vegetation and soils. It is thus imperative to better manage grazing intensities and maintain productivity of dryland ecosystems.

The impact of varying stocking rates together with climate change scenarios (IPCC A1B and B1 downscaled to the basin of Ouarzazate, IPCC 2007) was analyzed by adapting the spatially explicit ecosystem model SAVANNA (Coughenour 1993). It computes herds of sheep, goats and dromedaries with grazing on herbaceous, shrub and tree biomass with a high spatial resolution. Plants are categorized into plant functional types (PFT). The model computes e.g. PFT's aboveground net primary production (ANPP) with PFT inherent parameters such as photosynthesis. Results are either plotted as time curves or spatial maps (resolution 1 km^2). Hydrological parameters and interactions on plant group species level are simulated, too. Model runs were based on livestock densities from census data. High animal numbers in the early 1980s resulted from higher rainfall in the late 1970s and were reduced rapidly over dry years. Although rainfall decreased further over the last decade of the 20th century, figures for sheep plus goat remained at a comparatively high level of about 800,000 heads (see Fig. V.1.5). Real stocking rates and precipitation are used to simulate a baseline scenario in the model.

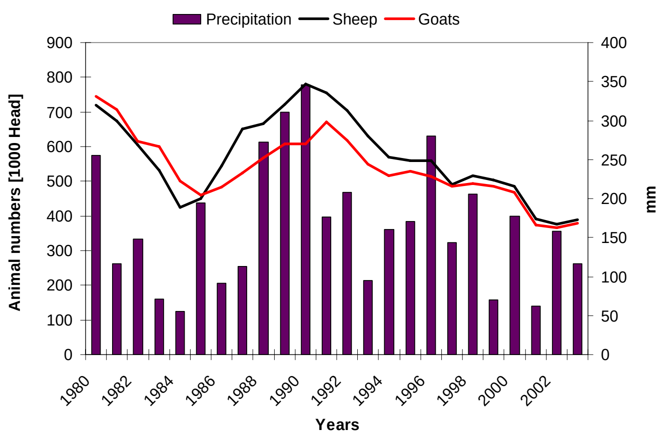

Fig. V.1.5: Development of annual livestock numbers (hundred thousands) by census data for the Province of Ouarzazate 1980-2003 and precipitation data of the climate station OZZ (Source: ORMVAO 2005).

The SAVANNA baseline model run (Fig. V.1.6) shows how biomass levels are reduced due to decreasing precipitation and high animal numbers. Total biomass increase in the course of one year is parameterised towards the maximum biomass at flowering in autumn. The new annual biomass development is calculated mainly on precipitation data. The first five years of simulation must be considered as a model 'warm-up' phase, and only the subsequent years should be taken into account. Total biomass increases with rainfall, and the model computes a slight increase of animal numbers, too. At the end of the 1990s, biomass amounts maintain a level of approximately 200-300 kg ha^{-1} (used for baseline runs).

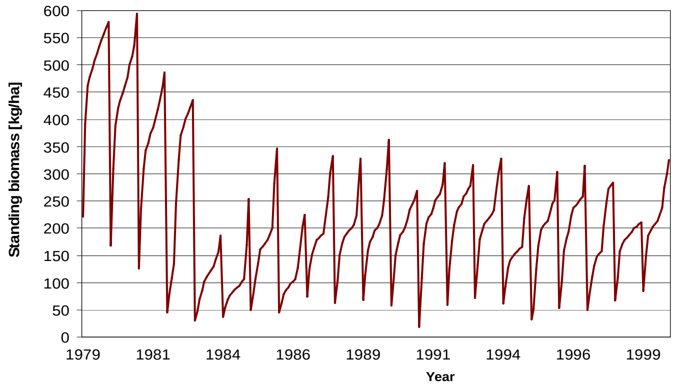

Fig. V.1.6: Simulated monthly total standing biomass [kg ha^{-1}] for the basin of Ouarzazate.

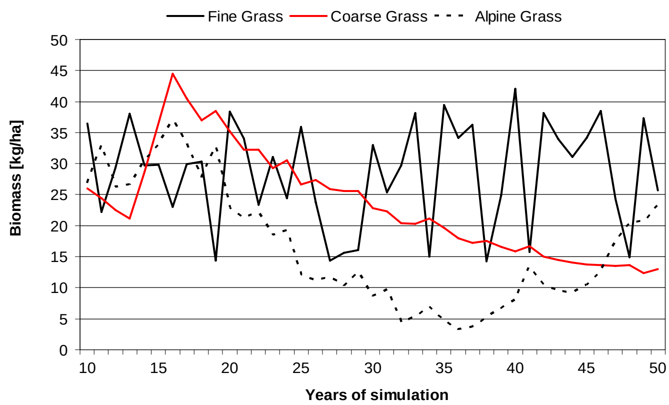

Fig. V.1.7: Development of fine, coarse, and alpine grass, accumulated to annual leaf biomass [kg per ha] for a simulation period of 40 years

The development of herd sizes was calculated on the basis of input data about abundance and growth of vegetation where the model predicts biomass production [kg ha-1] for herbaceous plants (grass), shrub and trees. Each of these layers is subdivided into different plant types (e.g. for herbaceous PFT's into fine, coarse, and alpine grasses). The simulated evolution of plant types is shown in Fig. V.1.7). The types 'fine grass' and 'alpine grass' are highly preferred in animal diets. While the 'fine grass' keeps a constant level of biomass throughout the simulations, 'alpine grass' is predicted to decrease, likely due to its presence in fewer niches in the study area. 'Coarse grass' is predicted to decrease slightly due to climate change despite its low digestibility.

In general, the model runs suggest a higher impact of stocking rates on herbaceous and shrub ANPP than climate change. Furthermore, heavily grazed PFT groups such as “fine grasses” are able to maintain a constant stock of biomass development. The unexpected decrease of unpalatable plants during simulation has to be re-assessed for the Drâa catchment.

The evolution of nitrogen budgets, plant water consumption and animal conditions are likewise computed by the SAVANNA model. Model calculations of the variation of climate scenarios and stocking rates help us to evaluate the resilience of vegetation towards grazing impacts. Model runs may be used to determine specific highly vulnerable and sensitive areas. Vegetation cover and abundance results may be successfully integrated into economic models.

Conclusions

Two important links between resource use and livelihood security were described in this section: while cropping in the Drâa oases heavily depends on water availability, transhumant livestock husbandry relies on land and vegetation productivity. The two main agricultural production modes are practiced by different ethnic groups with different organizational forms, using different technologies, and producing different products. An important common characteristic is that both production modes rely directly or indirectly on rainfall, and therefore are heavily exposed to short-term weather variability. Moreover, both production modes must manage problems resulting from the “tragedy of the commons” (Hardin 1968). In the case of farmers, water for irrigation is the contested resource, while herdsmen have to manage pastures in a sustainable way.

The livelihoods of the inhabitants of the Drâa basin were more heavily dependent on agricultural production in earlier times than they are today. As discussed in Chapter V.4, labor migration and tourism increasingly help to diversify the sources of income for farm and pastoral households. The impact of these additional sources of income on the intensity of resource use remains an open question. Several different incentive patterns might conceivably be at work here, depending on the resource endowment of the individual farm household and the source of additional income.

First, non-farm income might substitute farm income. This may be the case in families where labor resources to continue farming have become scarce after the outmigration of young members that leaves only child-raising women and the elderly in the village. If this were the case, farming would be largely abandoned, and the land or water rights of the family would be leased out, not leading to an additional use of resources. However, if the labor resources of the household are still idle, the household might use additional monetary resources to invest in non-farm economic activities, education, or housing. In terms of resource use, this alternative would also be largely neutral. If, however, farm households decide to invest in technology that enables a more effective extraction of resources, such as motor transport during transhumance or motor pumps for groundwater extraction, resource use and the resulting pressure on local and regional resource endowments might increase. This latter result becomes more likely the greater the preferences of resource users for continuing the resource-using activities. To properly farm their own fields or to own a large livestock herd usually raises the reputation of family heads among their peers and strengthens the influence of the family in local decision-making bodies. The increasing number and use of motor pumps in the Drâa oases, as well as the rising importance of the motorized transport of livestock during transhumance, both indicate that land and water resources will remain under pressure despite their diminishing importance to total family income.

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V.2 Wasserbezogene Probleme / *Water-related Problems*

Seasonal Snowmelt Runoff Forecast for the Management of the Mansour Eddahbi Reservoir

At the Mansour Eddahbi reservoir all tributaries of the Central High Atlas Mountains join. Large parts of the winter precipitation in the mountains fall in the form of snow. For the water availability in the Drâa Valley (quantity and quality of drinking water, quantity of irrigation water, water release for downstream irrigation) the short term as well as the long term development of the precipitation and snow melt is important. For management purposes it is important to know how much water will be available in the next months from snow melt. For long-term planning the effect of Global Change on the water resources has to be quantified to be able to develop strategies coping with future water scarcity.

The effects of climate change on the hydrological cycle and on the discharge of the tributaries of the reservoir are modelled with the Snowmelt Runoff Model SRM (Martinec et al., 1998). The overall contribution of the tributaries as well as the refill level of the reservoir are calculated considering water losses from the river bed within the Monitoring Tool PRO-RES (PROnostic de la fonte de neige pour un barrage REServoir; PROgnosis of snowmelt runoff for a water REServoir). The statistical forecast of the weather from late winter to the following summer is performed by the weather generator SMGHydraa (Statistical Model for the Generation of Climate Data for Hydrological Applications in the Drâa Region). The statistical forecasts are essential for the estimation of the snowmelt period and precipitation.

The regional discretisation follows the distribution of the hydrological stations of the regional water authority (Service Eau de Ouarzazate). In the short term forecast mode, daily snow cover is required as input. To derive these values from satellite data, daily MODIS images were used and analysed. The resulting snow masks are intersected with the zoning of the Upper Drâa basin resulting in a table with the percentage snow cover within the different altitudinal zones. Currently, the satellite data base consists of about 400 images representing the snow cover periods from 2001 to 2008 and is updated periodically.

Climate scenarios until 2020 calculated by REMO (Paeth et al., 2005) based on IPCC SRES scenarios A1B and B1 were downscaled to the Drâa basin, including the High Atlas Mountains and the Drâa Valley. The climate scenario data provides a statistical representation of the possible future climate. These statistical results cannot be taken as real predictions to distinct time periods. Therefore the reservoir inflow modelled on this data base is only a representation of inflow characteristics but not related to one of the specific years 2001 to 2020.

Modelled reservoir inflow shows a high inter-annual variability during this period (Fig. V.2.1). Regarding the results for climate scenario A1B, there is a trend to extremer periods (wetter as well as drier) in the second decade, whereas the number of medium wet periods decreases (Fig. V.2.2). In climate scenario B1 the monthly mean reservoir inflow volume (2001-2020) is 12.4 Million m³, which is 10 percent higher than for climate scenario A1B (11.3 Million m³). In B1 the standard deviation is 14.8 M m³, compared to climate scenario A1B with 13.7 M m³. The higher inflow value for climate scenario B1 can be interpreted as a minor change in climate compared to the climate scenario A1B scenario.

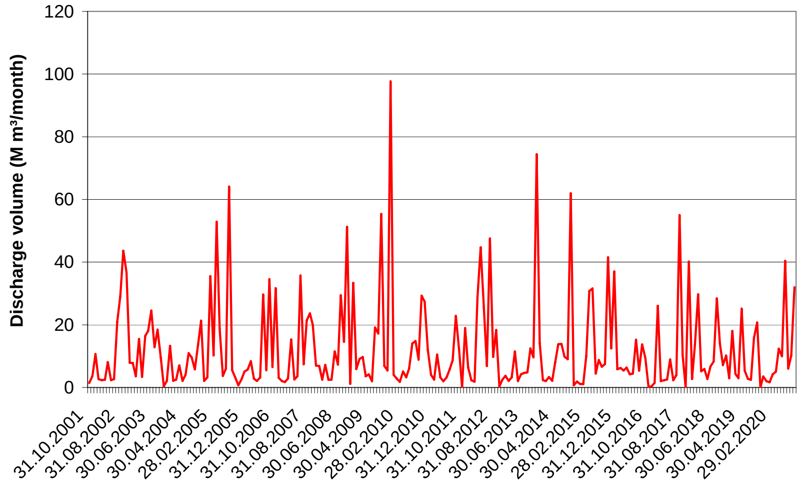

Fig: V.2.1: *PRO-RES* modelled monthly mean reservoir inflow for the period 2001-2020 based on climate scenario B1 (regionalization of climate data performed by the tool *SMGHydraa*).

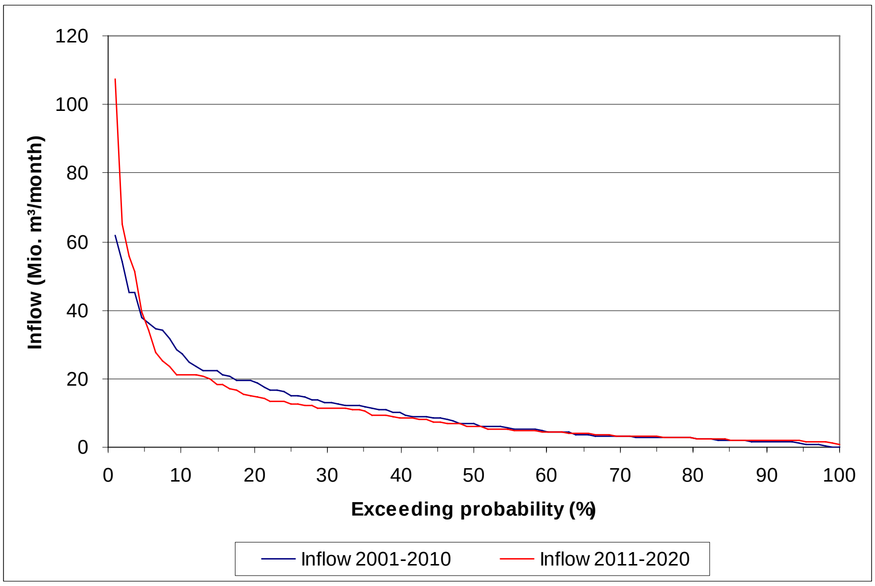

Fig. V.2.2: Exceeding probability of the monthly mean reservoir inflow for 2001-2010 and 2011-2020 modelled with PRO-RES based on climate scenario A1B (regionalization of climate data performed by the tool SMGHydraa).

Climate change effects on the water resources in the Upper Drâa catchment

In this study the model system SWAT (Arnold et al., 1993) has been adapted and applied for quantifying the effects of climate change on the water resources in the Upper Drâa region. Since both climate scenarios A1b and B1 do not evoke significantly different trends for Morocco (Born et al., 2008), all six ensembles are used for a combined scenario analysis within this study comparing the periods 1970-2000 and 2001-2030. While temperature increases about 0.3-0.8 °C, changes in precipitation vary to a larger extent, exhibiting distinctions between the basin and the mountainous region.

As pointed out before, the weather generator SMGHydraa has been developed which fits data to orographic characteristics (elevation, exposition etc.) not considered within REMO. Anyhow model biases (25% more precipitation simulated by REMO compared to measurements) remain in the data and therefore prohibit direct use within a hydrological model. Consequently four different downscaling techniques have been used to generate usable time series (Tab. V.2.1). As proposed by Arnell u. a. (2003) climate change effects are derived from the comparison of control runs (1971-2000) and scenarios (2001-2030). The measured data of the period 1978 to 2007 is considered equivalent with the period 1971-2000 and therefore referred to as "baseline scenario". The changes in climate as computed by REMO are added to the measured data and referred to as climate scenario: A relative decrease in precipitation has been converted into a decrease of the number of wet days, whereas a relative increase has been added to events in the respective month, resulting in a scenario with rainfall intensities comparable or higher than in the baseline scenario (A). The second approach converted relative changes into relative changes of each event, resulting in decreased intensities of the events (B). Within the third approach absolute changes of monthly precipitation have been added to single events, leading to (slightly decreased) intensities comparable to the baseline scenario (C). A fourth approach directly used the climate change scenarios without any downscaling, therefore only relative changes in the model output can be analyzed (D). Knowing the deficiencies of each single approach, the spread of results using different downscaling techniques is assumed to at least confine the range of reasonable results. Though single components of the water balance can be assessed easily using SWAT, inter-annual variability that may change as well in future periods can not be considered. Since this approach does not account for changes in inter-annual variability, but maintains variability as in the baseline scenario, in this study no analysis of future time series is carried out. Instead annual exceedance probabilities and climate change induced effects on the annual water balance will be presented.

Fig. V.2.3 displays the development of annual discharge exceedance probabilities in the Upper Drâa catchment for the periods 2001-2030 compared to 1971-2000. The uncertainty range includes the second and third quartile of the 24 scenarios (6 ensembles x 4 downscaling approaches). It is likely (according to the nomenclature proposed by the IPCC this means a likelihood of occurrence greater than 66%) that discharge generally decreases. There are no particular trends for extreme years (dry or wet). One can regard 300 Mm^3/year discharge into the reservoir as an essential threshold since 250 Mm^3/year are required for irrigation of the Middle Drâa oases (Ministère des travaux publics 1998) and about 50 Mm^3 can be accounted for as evaporation losses and drinking water supply from the reservoir (though this number highly depends on the filling level of the reservoir). In the baseline period this threshold has been exceeded in 48% of the years, whereas in the scenario the threshold is exceeded in only 31% of the years. The annual water balance changes are summed up in (Tab. V.2.2 and Fig. V.2.4). The results given there are from at least 18 out of 24 simulations.

Table V.2.1: Downscaling techniques for scenario analysis

Downscaling	Baseline	Change in monthly rainfall	Change in monthly temperature	Character
A	Measured	Decrease: Number of wet days Increase: Relative per event	Absolute	Higher intensity
B	Measured	Relative per event	Absolute	Lower intensity
C	Measured	Absolute per event	Absolute	Normal
D	Simulated	Direct use of model data		As in scenarios

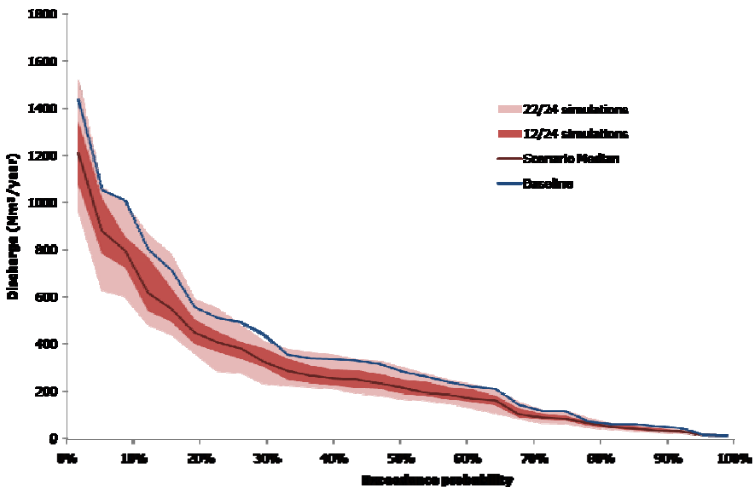

Fig. V.2.3: Development of annual discharge exceedance probabilities in the Upper Drâa catchment under climate change (1971-2000 and 2001-2030).

Precipitation is likely to decrease by at least 6% with a median of 10%. The projected temperature increase strongly affects snowfall, therefore its decrease is the strongest signal in the scenario results: Snowfall is likely to decrease by 13% (median=17%). Runoff will decrease by 10% (median=16%). The relative importance of hydrological processes does not undergo a substantial change, though a slight shift in the runoff composition can be observed. Surface runoff decreases in favour of baseflow, which can be attributed to the lower intensity of the scenario rainfalls, compared to the baseline period.

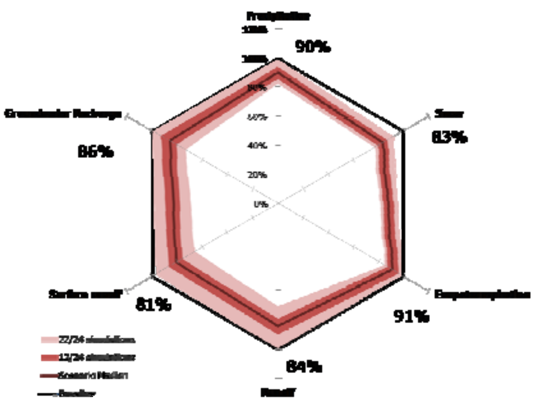

Fig. V.2.4: Development of annual water balance components in the Upper Drâa catchment under climate change (1971-2000 and 2001-2030), light red indicates the surrounding 83.3% (22 out of 24 scenarios), dark red indicates the 2nd and 3rd quartile (12 out of 24 scenarios).

Table V.2.2: Water balance of the Upper Drâa catchment (14981 km²), modeled with SWAT (baseline scenario 1971-2000 and scenario 2001-2030).

		Baseline	Fraction of Precipitation	Scenario (Median)	Fraction of Precipitation
Precipitation		212.5		191.0	
	Snow	26.0	12.2%	21.6	11.3%
	Rain	186.5	87.8%	169.4	88.7%
- Evapotranspiration		168.6	79.3%	153.0	80.1%
- Direct GW recharge		3.5	1.6%	2.9	1.5%
= Runoff		40.4	19.0%	34.1	17.9%
	Surface	19.8	9.3%	16.0	8.4%
	Interflow	1.1	0.5%	1.1	0.6%
	Baseflow	19.5	9.2%	17.0	8.9%
- Indirect GW recharge		4.5	2.1%	4.0	2.1%
= Channel Discharge		35.9	16.9%	30.0	15.7%
- Irrigation		11.1	5.2%	10.1	5.3%
= Reservoir inflow		24.9	11.7%	19.9	10.4%
Total GW		8.0	3.8%	6.9	3.6%

Considering the uncertainties, the effects of different ensemble runs and different downscaling approaches have been compared: 68% of total uncertainty in the scenario discharge can be attributed to the use of different ensembles, whereas the remaining 32% are due to the use of different downscaling techniques.

Scenario calculations for the groundwater resources in the Middle Drâa valley using the SDSS IWEGS

The spatial decision support system IWEGS (Impact of Water Exploitation on Groundwater and Soil) combines groundwater budget assessment with soil salinity modeling. The model Sahys-Mod (ILRI, 2005) is therefore coupled to the groundwater budget model BIL. This coupling includes also tools to preprocess the domestic water consumption and the crop water demand which are important components of the groundwater balance. IWEGS is used to evaluate the need of further investigations on groundwater and soil on the scale of the six Drâa oases of the Middle Drâa valley downstream of the Mansour Eddahbi reservoir. IWEGS can estimate long-term changes of groundwater availability and soil salinity. The output of IWEGS is the lumped annual filling level of the aquifers beneath each oasis. The soil salinity is given as lumped annual electric conductivity (in the saturation paste) for each oasis. IWEGS is capable of calculating socio-economic scenarios.

The climatic scenarios for the groundwater resources of the middle Drâa valley are derived from the REMO – modelling of climate change (Paeth, 2005; Born et al., 2008). Available stream flow and regional precipitation determine the scenario projections. Because water availability in the Middle Drâa valley is strongly dependent on the filling level of the reservoir Mansour Eddahbi, annual stream flow is derived from the hydrological modeling in the upper Drâa catchment (see before). Consequently, all 24 scenarios are used to estimate the annual water availability for the Middle Drâa valley. The climate scenarios suppose a substantial decrease in released water from the reservoir (Fig. V.2.5). The mean annual outflow in the period 2001 – 2030 is simulated to be 32 Mm³ less than in the period 1974 – 2000. Thereby especially the extraordinary high releases are expected to decrease whereas periods with extremely low release amounts will increase.

The three socio-economic scenarios developed in IMPETUS (marginalization (M1), rural development (M2) and business as usual (M3)) were used in this study. The scenario of marginalization (M1) uses the water consumption as a response indicator for increasing migration and water pricing. Thus domestic water consumption is assumed to decrease by 10 %. At the same time cropping intensity stays low and agricultural water consumption remains the same as in the base line model run. The scenario of rural development (M2) considers growth of tourism and decreasing migration resulting in increasing domestic water consumption. Accordingly the domestic water use in rural areas is assumed to rise by 20 % and in urban areas by 40 %. In the base line model run the cropping area is adapted to surface water availability. Thus cropland is reduced in dry years and reaches its maxima after wet years. In this scenario the cropping area has to be preserved on a level of 70 % of the maximum extent of the arable land to feed the inhabitants. Simultaneously drip irrigation is implemented to save water. Drip irrigation is implemented by improving the irrigation efficiency by 20 %. The successive implementation follows a linear trend. Thus drip irrigation is applied on 50 % of the cropping area after 30 years. The scenario following business as usual (M3) takes into account population growth and urbanization as linear trends. Consequently the domestic water consumption is assumed to develop according to the number of inhabitants. If population increases the cropping area is assumed not to fall below 50 % of the maximum of the arable land to assure subsistence agriculture in the middle Drâa valley.

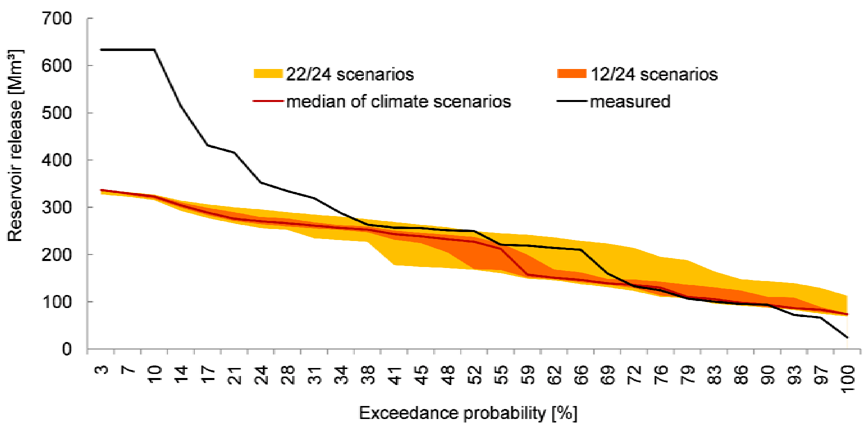

Fig. V.2.5: Future development (2001-2030) of the amount of water releases from the reservoir following the climate change scenarios simulated with SWAT (see before) compared to the period of the base line model run (measured).

As a consequence of the hydro-geological heterogeneity the six oases aquifers react different depending on the modified boundary conditions derived from the climate scenarios (Fig. V.2.6). Furthermore the steep climatic and altitudinal gradient along the oasis chain of the Drâa has an impact. Thus the global view on the results relating to the entire middle Drâa valley is skewed concerning the water balance components for all model runs. Accordingly for the interpretation of the scenarios the aquifers are evaluated separately and exemplary phenomena of selected oases are presented.

The aquifers of Mezguita, Ktaoua and Mhamid are affected by significantly reduced groundwater availability. For Tinzouline, Ternata and Fezouata the signal of climate change is not that clear as for the other three aquifers. The strongest influence of climate change is observed for very high and very low filling levels of the aquifers (Fig. V.2.6).

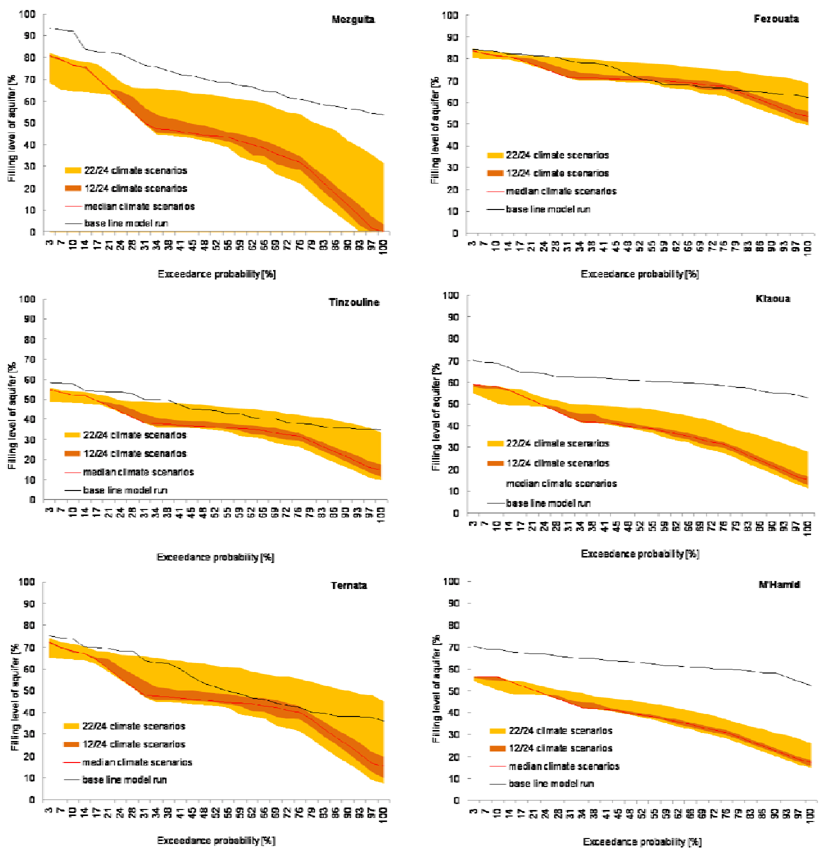

Fig: V.2.6: Results of climate change scenarios (2001-2030) compared to the base line model run (for Mezguita, Tinzouline and Ternata (left column) and Fezouata, Ktaoua and Mhamid (right column).

Soil salinity in 2030 is predicted to be higher for all oases under climate change conditions than under recent climate following the SahysMod simulations (Fig. 5.2.7). The climate change signal seems to be significant as the uncertainty band originating from the different climate change scenarios does not superpose with the baseline simulation. Climate change accounts for an increase in soil salinity of up to 5 mS/cm compared to recent climate conditions. The signal (difference to recent conditions) is strongest for Fezouata and lowest for M'Hamid. Groundwater salinity behaves in correspondence to soil salinity. The reason for the increase in salinity is the lower input of relatively low-saline surface irrigation water and thus an increased use of groundwater for irrigation purposes. Therefore the transport of salts out of the rooting zone with the low-saline surface water is reduced. Additionally the quality of the groundwater declines due to a lower input of percolating river water diluting the aquifer and a higher abstraction of water.

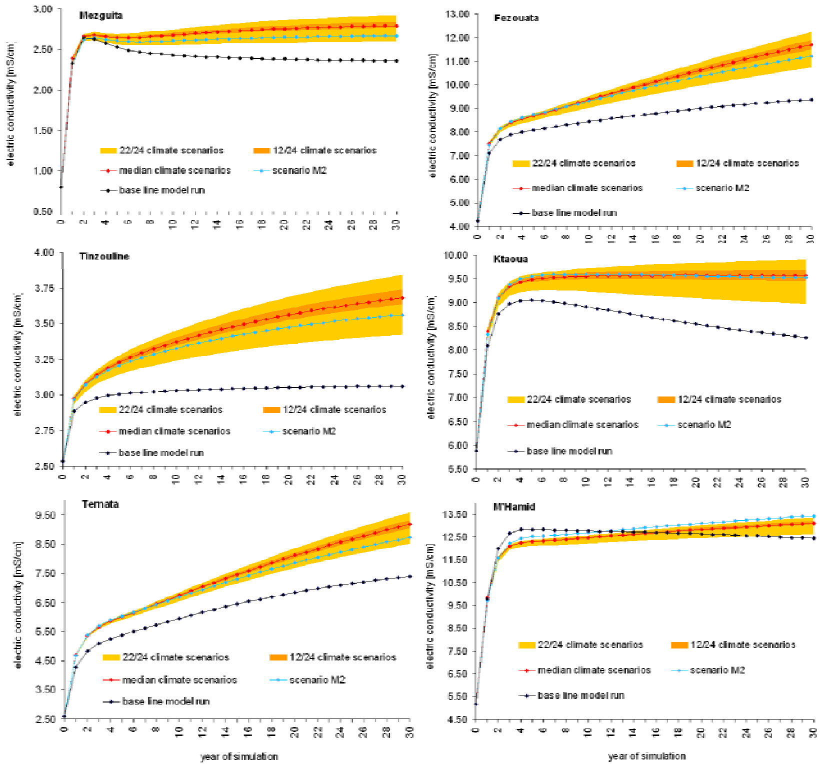

Fig. V.2.7: Results of climate and socio-economic change scenarios (2001-2030) for soil salinization compared to the base line model run for the six Drâa oases (mind varying scaling for electric conductivity in this figure). The first two years have to be regarded as warm-up period for the SahysMod model.

In the socio-economic scenario M1 (**marginalization)** a slight increase in groundwater availability is computed at the regional scale (Fig. V.2.8). As no changes concerning agricultural practices are assumed in this scenario, changes in soil and groundwater salinity at the regional scale are negligible. Slight effects can only be expected at the local scale if the non-saline lateral afflux increases due to decreasing drinking water abstraction. The scenario of **rural development** (M2) shows that the groundwater reservoirs would run dry during drought periods except Fezouata and Mhamid (not shown). The implementation of drip irrigation saves water and mitigates the drought impact concerning water availability. Further estimations show that if drip irrigation is applied on 60 % of the cropping area the groundwater reservoir could be preserved.

The application of drip irrigation leads to an increase in soil salinity compared to the recent conditions (Fig. V.2.7). The signal is again strongest in Fezouata but lowest in Mezguita. Nevertheless its influence is nearly as high as the climate change impact for the five upper oases and even stronger for M'Hamid. The reason for the increase is the diminished amount of irrigation water applied to the fields and thus the reduced transport of salts out of the rooting zone. This leads to an accumulation of salts in the soil (Fig. V.2.7). Thus for the soil resource the application of drip irrigation is not favorable at least as long as no counteracting measures such as soil washing are carried out. Accordingly drip irrigation affects groundwater and soil in opposite directions. Groundwater resources can be preserved while soil quality declines.

The scenario assumed as business as usual (M3) reveals decreasing groundwater availability due to increased domestic water consumption per capita in combination to population growth (Fig. V.2.8). Comparable to the marginalization scenario no changes in agricultural management are expected in this scenario. Thus salinity of the soil and the aquifer is only affected at the local scale when the lateral afflux of non-saline water from the surrounding mountains is reduced due to higher drinking water extraction. But this effect is not influencing salinity at the regional scale.

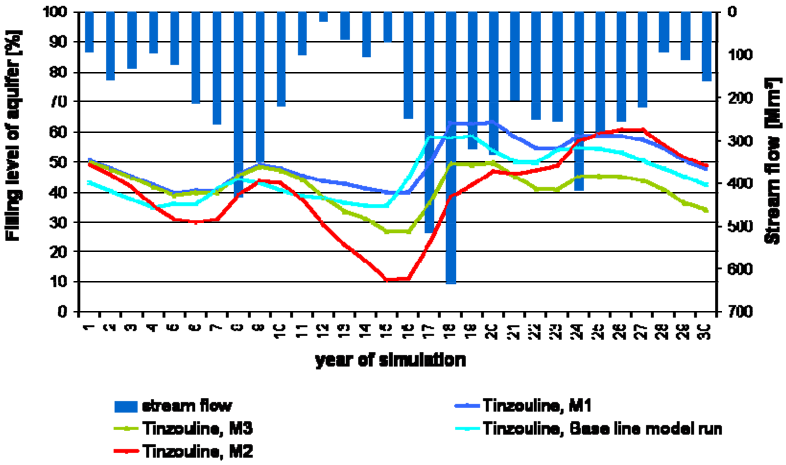

Fig. V.2.8: Scenario results of socio-economic changes (M1, M2, and M3) over 30 years and the result of the baseline model run for the annual filling levels of aquifer of Tinzouline with the stream flow of the Drâa.

Conclusions

The scenarios calculations reveal a decline in water resources and therefore an increase in water scarcity. This is on one hand due to climate change although climate signals are not very strong. On the other hand, socio-economic scenarios show an impact of management strategies on soil as well as water quality and water quantity. This is more concise in the Middle Drâa valley as water demand is driven by socio-economic constraints.

To assess the effects of Global Change on the investigated catchment a number of Spatial Decision Support Systems have been developed. The system PRO-RES can be used for a seasonal forecast of the filling level of the reservoir Mansour Eddahbi which enables a foresighted management of the water resources. For the Upper Drâa basin the system HYDRAA (not shown) has been developed which combines the SWAT model described before, water demand of the oases upstream of the reservoir and the reservoir itself. Unmet water demand can be determined for selected periods and locations. The system IWEGS is designed for the oases downstream of the reservoir and considers hydro-geological processes, irrigation as well as domestic water demand

and soil and groundwater salinization. All systems are calibrated, validated and carefully tested. Because they can be adapted to future data availability like new climate scenarios these tools may help decision makers in evaluating options for action.

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V.3 Landnutzung und Landbedeckung / *Land Use and Land Cover*

Introduction

Growing human populations living in drylands and global climate change increase the land use pressure (Meze-Hausken 2000). Unsustainable forms of land use lead to land degradation, which is manifested by declining soil fertility, increasing erosion, deforestation, and loss of biodiversity (Eswaran et al., 2001). Ultimately it leads to a reduction or loss of the biological or economic productivity. Thus, land degradation increases the vulnerability of the local populations that depend on these systems for their livelihoods. Given the number of people affected, it is ranked as one of the most severe environmental problems today. The debate on land degradation is, however, relatively polarised, particularly for sub-Saharan Africa (Prince et al. 1998; Dougill et al. 1999; Olsson et al. 2005) and for the Western Mediterranean (Martínez-Fernández and Esteve 2005). Recent estimations state that land degradation affects about 20 percent of global drylands (Millennium Ecosystem Assessment 2005). One of the outcomes of the degradation process is a reduced capacity of degraded environments to absorb disturbances, such as droughts and floods (Rockström 2003). Climate change projections indicate an increased variability of rainfall in drylands, leading to a higher frequency of such extreme events wordwide in general (IPCC 2001) and in Southern Morocco in particular. Land use in Morocco's Drâa region has to cope with these substantial changes in the next decades.

In the oases of the Drâa catchment, a high spatio-temporal variability of precipiation is partly buffered by natural storage and by human management (see Chapter V.2). The vast areas outside the oases are used as rangelands. Here water resources and their variability can only be managed indirectly, i.e. via a management of the vegetation and its natural resources fuelwood and forage. To understand effects of direct and indirect water resource management on system functioning and resilience, local land use strategies have to be analysed. Here we aim to identify key traits of a pastoral land management which slows down land degradation, and mitigates negative effects of extreme weather events in the Drâa region.

Too much rain: The case of severe rainfall events

If large amounts of rainfall come down during a short period of time, the resulting severe rainfall may cause considerable damage to environmental and agricultural resources. We used extreme value analysis applied to the scenario output of nested climate models to predict changes in the frequency of days with severe rainfall for the Drâa region (Paeth et al. 2009). Ensemble runs allowed constructing rainfall time series from 1960-2050 for Northern Africa (see chapter II-5.3.1). The return values of 10-year recurring events (Born et al. 2008) show a slight decrease in the southerly, arid regions but an increase in the upper Drâa catchment. Although the annual mean rainfall is expected to decrease slightly and the occurrence of dry periods becomes more frequent, the frequency of extreme rainfall events may increase under future climate conditions.

The negative effects of severe rainfall events are floods and soil erosion by water. In this study, erosion risk is estimated applying the model PESERA (Pan European Soil Erosion Risk Assessment. Based on the PESERA model, the SDSS SEDRAA (Estimation of soil erosion risk in the

Drâa region) is developed to assess the impacts of climate and land use changes on soil erosion risk. The user is able to choose a climate scenario and simulation period or the measured climate data and to alter land use in two different ways. He can either choose regions via criteria query, e.g. 'alter the land use in regions with less than 10° slope inclination', or via graphic choice. Possible land use changes are either changing the vegetation type, or due to pastoral land management by defining a reduced impact of the vegetation by grazing.

As PESERA calculates mean long-term erosion rates for climatic periods, the climate data is subdivided into four periods of 15 years each. Results of the future scenarios are compared to the results of the reference period 1960-2000 calculated from climate models. Using the modelled climate data, PESERA model runs leads to an increase in erosion up to 2050 compared to the reference period 1960-2000. The mean erosion rate over the whole catchment increases by 21 ± 17 % in the period 2035-2050 compared to the past (1960-2000), but shows a high spatial variability. As both total precipitation and the number of rainy days will decrease (see above), the mean precipitation per rainy days stays nearly constant. The higher temperatures together with reduced precipitation lead to a reduced vegetation cover. Furthermore the variability of daily precipitation substantially increases which hints to increasing surface runoff. Thus the higher erosion rates are a combined result of a sparser vegetation cover, and more frequent events of severe rainfall.

Land use can either intensify or attenuate the negative effects of higher rainfall intensity. Here we aim to quantify the impact of changing human land use activities on soil erosion rates, using the IMPETUS socio-economic scenario approach (see Chapter III.3). Neither changes in land use such as an expansion of agricultural area, nor direct measures of erosion control such as afforestation efforts can be explicitly considered in these scenarios. Thus we concentrate on (i) changes in pastoral land management and (ii) changes in firewood extraction, and connect them to specific scenarios. In scenario M1 "Marginalisation" the number of animals in the catchment is presumed to stay constant. Due to rising energy costs, firewood extraction increases. Thus an increased vegetation reduction in the vicinity of villages is assumed for the simulation of scenario M1. In scenario M2 "Rural development" livestock numbers are supposed to decrease in the rural areas of the IMPETUS scenario regions "High Atlas" and "South" because less people follow a nomadic lifestyle. Animal numbers increase in the IMPETUS scenario region "Basin of Ouarzazate" due to the vicinity to markets. Thus the reduction of vegetation by grazing is presumed to increase here, but to decrease in the High Atlas and South for the simulation of scenario M2. In scenario M3 "Business as usual" no changes are assumed to occur.

In the "Marginalisation" scenario, mean soil erosion in the whole catchment is increased by 27 %. This seems to be a substantial increase, but it has to be taken into consideration that 55 % of the catchment's surface lies within a 5 km radius around villages (Fig. V.3.1, right). For a "Rural development", the simulation leads to a reduction of the mean erosion rate by 54 %. Grazing pressure is reduced by 73 % of the catchment's surface. Thus the protection of vegetation in the High Atlas and Antiatlas mountains reduces the mean erosion rate in the catchment sufficiently to outbalance the increase in grazing pressure and thus erosion in the Basin of Ouarzazate (Fig. V.3.1, left).

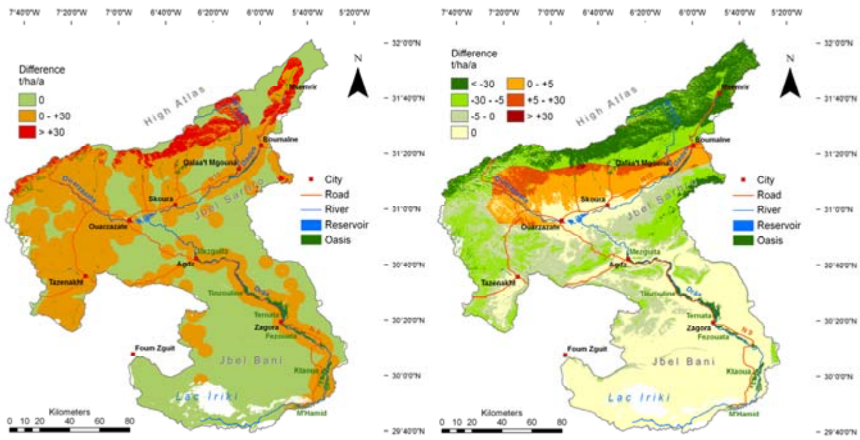

Fig. V.3.1: Differences between erosion rates of the IMPETUS baseline scenario, and the socio-economic scenarios M1 (left) and M2 (right).

In a next step, the scenarios of climate and land use change are jointly simulated to assess their combined impact on soil erosion rates. Results are compared to the reference period 1960-2000 and to the future climate without land use changes. If the climate change impact is combined with the scenario "Marginalisation", a further aggravation of the erosion problem due to human impact occurs (Fig. V.3.2). High energy costs force the inhabitants to increasingly use wood as energy source. Together with the higher probability of severe rainfall events, this leads to an increase in erosion of 64 % until 2050. The separate climate change effect accounts for a surplus of 25 %, thus human impact exceeds the climatic impact. For scenario M2 "Rural development" combined with the climate change scenario the model simulates a reduction of erosion of 25 % compared to the reference period. Comparing the combined simulation with the climate change effect, the human impact reduces erosion rates by 50 %. Hence a reduced grazing impact compensates for the climate change effect on soil erosion rates.

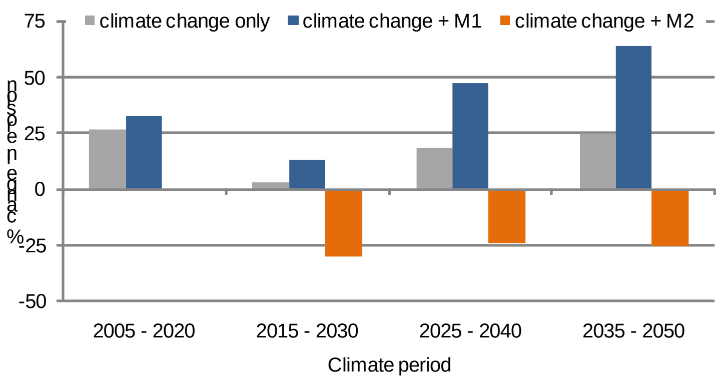

Fig. V.3.2: Combined effects of climate change and socio-economic scenarios compared to the reference climate period and the climate change only scenario as calculated by the PESERA model for the whole Drâa catchment.

Our study indicates an accelerated erosion due to effects of climate change. Higher erosion rates will occur because of a reduced protective vegetation cover and a higher rainfall variability. Range management is potentially able to outweigh the negative effects of climate change when rural development in the Drâa catchment is assumed. It could also aggravate the problem if further marginalisation took place. Thus range management has a strong impact on future erosion risk and may serve as an anti-erosive measure.

Too little rain: The case of meteorological drought

Negative rainfall anomalies may lead to a shortage of water with the extreme event of a meteorological drought. The detection of a meteorological drought can be done with the aid of the Standardized Precipitation Index (SPI; McKee et al. 1993). The resulting SPI series inform about wet conditions (positive values) or dry conditions (negative values). Empirical limits for droughts are often defined by thresholds of -1.7 (drought) and -2.2 (extreme drought). SPI calculations for the Drâa catchment (1900 to 2050) indicate a remarkable and statistically significant shift towards more dry conditions within the climate scenario SRES A1B. Second, extreme droughts tend to occur more frequently in the last thirty years of the climate simulation (Born et al., 2008).

A meteorological drought is translatable to higher levels of natural resource scarcity: first to the level of available fodder or food in the case of an agronomic drought, when soil moisture is depleted so that the yield of plants is reduced considerably; and second to the level of economic activities in the case of a socio-economic drought (Agnew and Warren 1996). A socio-economic drought in rangelands is triggered by scarcity of available forage. The effects of meteorological droughts in the Drâa catchment could – like in other drylands (McAllister et al. 2006) – be mitigated by an adaptive range management as practised by pastoralists. It has to cope with the temporal and spatial variability of natural resources, which is mainly driven by rainfall variability. Our case study is the range management of the Ait Toumert pastoralists, a small Berber fraction which has its pastures on the southern slopes of the High Atlas Mountains (for more information on this case study, see Capters V1 and V4). Their normative transhumance cycle runs along a steep altitudinal gradient, which reflects a gradient of climatic aridity, and rainfall variability. Mountainous pastures are used during the summer months, and lowland pastures during winter. The transition pastures are grazed during some months in spring and autumn (Fig. V.3.3). Whereas the large winter pastures are characterised by a high spatial and temporal heterogeneity of natural resources, these are less variable in space and time on the smaller summer pastures (Kemmerling et al. 2009).

We hypothesize that the occurrence of fodder resources which buffer rainfall variability will be mirrored in mobility patterns: (i) pastures with a high reliability of fodder resources are used more intensively; and (2) pastoralists in the Drâa catchment indirectly manage pasture reliability which is reflected in their mobility decisions. We match data on the relative abundance of species with a different life span on pasture types (Fig. V.3.4) as an indirect measure for pasture reliability, with socio-economic data on grazing frequency.

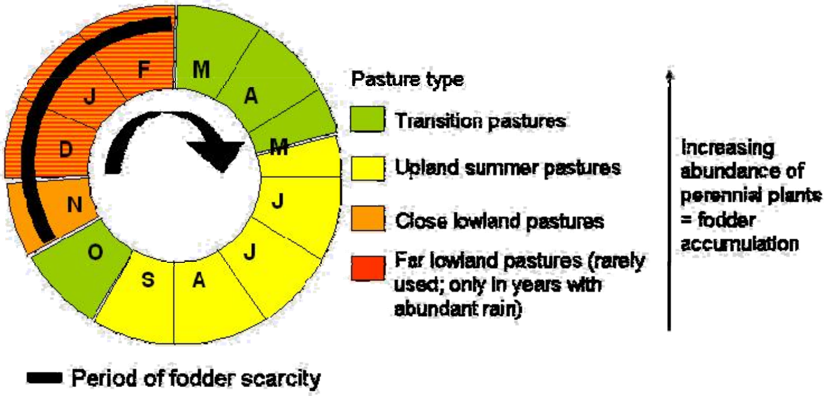

Fig. V.3.3: Annual transhumance cycle of the Ait Toumert pastoralists on their four pasture types, indicating the movements between pastures.

Local ecological knowledge on the quality and availability of fodder on different spatial and temporal scales is a key for pastoralists' management decisions (Kemmerling et al. 2009). Decision-making of pastoralists is linked to local perception of resource reliability. In our case study, the upland pastures which have a reliable proportion of long-living, perennial species (Fig. V.3.4). They are regularly grazed during spring, summer and autumn. Pastoralists are conscious about the unreliability of far lowland pastures where annual plant species are dominant. Their decision to move there largely depends on the resource availability in a particular year. Only in years with good rains, all households decide to move to these pastures, because herdsmen know that they will then find an abundance of herbaceous biomass for their livestock. In other types of years, only a certain proportion of pastoral-nomadic households move there. Instead, households stay on transition pastures where more perennial species occur compared to far-lowland pastures (Fig. V.3.4). Thus, mobility decisions of pastoral-nomads depend on the availability of fodder resources in general (i.e. the type of year), and specifically on the availability of fodder resources provided from perennial species: The less perennial species occur on a certain pasture, the more the movement to this pasture depends on the quality of the year, except for summer upland pastures.

Spatial patterns of range management have to be interpreted with respect to their functionality: A crisis management applied during drought times is backed by a reliability management in times with less scarce rainfall. Mobility may thus not only be a coping, but also a preventive strategy in accumulating or maintaining local fodder storage. The mobility patterns of the Ait Toumert allow an exploitation of the diversity of vegetation types along a steep altitudinal gradient, securing a continuous access to temporally highly variable resources. Forage accumulation is another essential management strategy applied by land users in arid environments, for example where certain areas are set aside for drought times (Bollig 2006). The pasture types with the highest amount of accumulated forage are the transition pastures and the close lowland pastures. These are the ones with sustain livestock with fodder during the scarce time of the year (which is, in the Ait Toumert system, the winter time, see Fig. V.3.3).

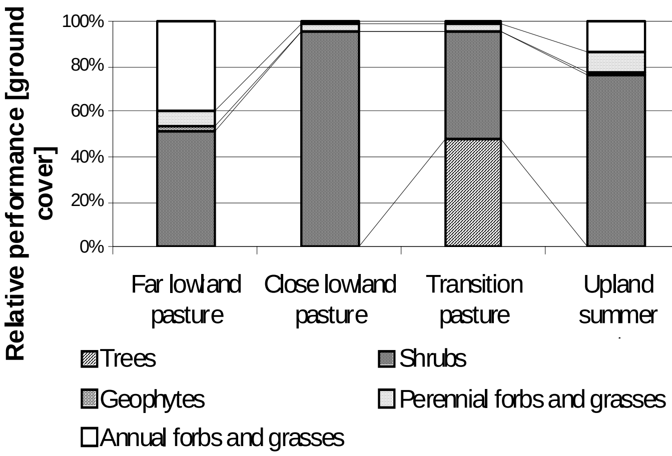

Fig. V.3.4: Standing crop of different life forms on the four types of Ait Toumert pastures arranged along a gradient of decreasing climatic aridity as well as rainfall variability. The life forms in the bars are arranged according to their life span (from long-lived trees to short lived annual forbs and grasses).

On the upland summer pastures, a highly reliable fodder production is reflected in a regular intensive use of this pasture type. However, a reliable production of palatable biomass is not only sought after but also maintained by means of the *agdal* system (for a description of the *agdal*, see Chapter V.4). It protects perennial species from grazing during the onset of the vegetation period when plant individuals are particularly sensitive to grazing, and have at the same time a high recovery potential. A second mechanism of promoting resource reliability is through an indirect protection of transition pastures in years with abundant rainfall. Only in years where rainfall is perceived to be 'good', local herdsmen move to their far lowland pastures, allowing a recovery of perennial vegetation on their – else intensively used – transition pastures (Kemmerling et al. 2009). The crucial importance of protecting pasture reliability through a resting in times when the vegetation's recovery potential is high has been reported to build resilience in other drylands (Colding et al. 2003, Frank et al. 2006). Ecological reliability is thus both sought after, and protected, via local mobility patterns (Roe et al. 1998; Ilahiane 1999). Perceiving reliability and adjusting management decisions to it is an important mechanism of resilience in this type of social-ecological systems. As an adaptive approach to dealing with uncertainty (Fernandez-Gimenez and Le Febre 2006), it increases the ability to cope with and regenerate from external shocks, such as droughts.

Naturally, the grazing impact of the local smallstock herds reduces the perennial vegetation cover beyond the densities on sites protected from grazing. During a recovery period of seven years, a significant amount of perennial biomass was accumulated on most of the Ait Toumert pastures (Baumann et al. 2009). The recovery is highest on the most productive transition pastures: Here more than 2,500 kg dry matter were accumulated per hectare. The protective perennial vegetation layer became three times as dense in this time. However, the degradation of the perennial vegetation can be much worse as observed on pastures close to permanent settlements (Baumann, unpublished data). In summary, the Ait Toumert invest into the ecological buffer of their pastures via (i) a delayed grazing of summer pastures (institutionalised in the *agdal* system), and (ii) allowing a regeneration of the intensively used transition pastures in years with abundant rainfall when local herdsmen move to lowland pastures.

An adaptive management of the perennial vegetation has important implications for the sustainability of local range management. It creates a functional connection between the effects of different extreme weather events. Because perennials effectively protect the soil from erosion (Nyangito et al. 2009), maintaining a certain density of perennial plants is an important anti-erosive measure (see further below). Besides pasture management strategies which promote fodder resource reliability, herd management during and after a drought may also play a crucial role in this context. In arid rangelands, droughts lead to frequent crashes of livestock populations (Vetter 2005). Due to a lagged response of livestock populations to fodder availability during and after a drought, vegetation has a certain time window to recover. To avoid a degradation of the natural resource base, it is crucial to allow pasture recovery in the years following a drought. If stocking rates are not significantly reduced shortly after drought times, the potential for accelerated erosion following the drought increases (Morton and Barton 2002). Thus, the risk of floods and erosion in the Drâa catchment is much higher if pastoral range management is not adapted to the spatio-temporal patterns of natural resource vulnerability. Besides this potential impact of drought on future impacts of severe rainfall, there exists also a connection between severe rainfall on future effects of meteorological drought.

Conclusions

The land management in the Drâa catchment mitigates drought effects on all levels of resource scarcity. Drought mitigation is – in the case of pastoralism – functionally achieved by a preventive natural resource management, particularly in times of abundant rainfall, by coping strategies during and after droughts, and through access to alternative income sources. Such an adaptive land management ensures the resilience of the whole social-ecological system in this highly unpredictable and vulnerable environment.

Although the pastoral strategies of natural resource management mainly aim at mitigating drought effects, they may, at the same time, somewhat mitigate the negative effects of high rainfall intensity, particularly erosion processes. Wind erosion, although an important process in semi-arid and arid regions, has not been dealt with here because of the great uncertainties in wind speed estimations from climate models.

We recommend that for reducing water erosion in the High Atlas region, adaptive range management strategies and more direct measures, such as small stone walls and stone terraces, should be combined. A protection of the vegetation might even outweigh the negative effects of climate change on water erosion. Furthermore, official drought mitigation measures should take into account the critical time after a drought when pastures and soils are particularly vulnerable to degradation. For example, it seems more feasible to support local herd owners by subsidizing the sale of livestock or to provide supplementary fodder after a drought than to provide fodder during drought times. Other strategies of drought mitigation could focus on market development and opportunities for livelihood diversification.

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V.4 Gesellschaft / *Society*

International and national migration

In the south of Morocco, in addition to the pressure on resources due to the demographic development, recurring periods of aridity during the past decades have damaged the agriculturally based economy. In the Provinces of Ouarzazate and Zagora natural resources are unequally distributed. In the High Atlas Mountains as well as in the Basin of Ouarzazate, water is not as scarce as it is in the Middle Drâa Valley, where water flow is controlled by the Mansour Eddahbi dam near Ouarzazate. Nevertheless, scarcity of rain has consequences in the whole area, so that labour migration is common among people living in communities in the High Atlas as well as in the Ouarzazate Basin or the Middle Drâa Valley. In addition to the increasingly scarce amounts of available irrigation water, the quantity and quality of domestic water have decreased. Apart from the direct negative impacts of the water crisis which is evident with respect to nutrition, hygiene, reproductive health, and the overall quality of life, indirect economic consequences such as increasing labour migration have severe impacts on the development of the region. Especially migration became a key strategy to sustain livelihood. Morocco is one of the foremost emigration countries worldwide, and has a large number of national migrants as well. The main reasons for national migration are the existing economic disparities within the country, with a prosperity gap between North and South. While the Atlantic coast in the North is the economic heart of the country, the South and especially the southern oases such as the Drâa Valley are economically marginalised.

Although most migration studies have so far focused on international migration, national migration must not be neglected. In the region under investigation, the number of migrants moving on a national scale outnumbers international migrants. That little attention is paid to national migration in recent migration studies might be explained by the negative image of national migration, called “exode rural” in Morocco. This neglect by scholars and politicians is founded in the low economic benefit of national compared to international migration, the theoretical focus on transnationalism, and the lack of data to quantify national migration. Even though national and regional migration affect a large number of people, comparative data about national migrants are scarce, because national migrants are not mentioned in the published versions of the national census data. This disadvantage could only be overcome through detailed local case studies which reveal various aspects of migration on a local scale. In our case study, national and international migration are regarded simultaneously, because national migration often is the first step towards international migration and, according to Skeldon, there are no substantial or logical differences between the two forms of migration (Skeldon 1997: 9f.).

The application of qualitative methods allows a better understanding of the social implications of labour migration, and provides a differentiated view of migrants’ motivations. While in many analyses the decision to migrate is interpreted as purely economically driven, it could be shown that reasons for individual migration decisions include social motivations as well. Hence familial situations, social positions in the village, questions of individual property, or personal desires of various kinds are equally strong reasons for migration as are unemployment, demographic pressure, or droughts (cf. Rademacher 2008b).

Local informants agree that in the beginning, migration was mostly triggered by the poor economic situation. But with an increasing number of migrants, the motivation to migrate became more diversified. Migration generates a positive feedback not only through financial remittances but also through the flow of information and news which Levitt calls “social remittances” (cf. Levitt 1998:926ff.). The more information about living and working conditions in the cities is available and the more contact points are known, the greater the willingness to migrate. Migration networks including relatives or friends living in the urban centres, as well as family members who take care of the property at home, obviously facilitate migration (cf. Massey et al. 1993:449).

Especially for young males migration offers a unique opportunity to prove manhood and responsibility for their (extended) families. But this commitment to the family can easily develop into an unwanted obligation, when regular money transfers or expected presents exceed the migrant’s financial means. The adherence to the traditional Arab concept of the family as a socio-economic unit, within which each member has the obligation to assure the whole family’s livelihood makes this obligation even more demanding, and individual success or failure turns into the success or failure of a whole family, with drastic consequences for social status (Barakat 1985, Rademacher 2008b).

Migration on the local scale

As a pilot community for migration studies, Ouled Yaoub, a village of 1,000 inhabitants situated 30 km north of Zagora in the Drâa Valley was chosen. Here the causes and effects of labour migration upon the socio-economic setting, particularly with reference to the different ethnic groups and the motivation of the migrants, were investigated. This marginal region is largely dominated by agriculture, and there is only a small industrial sector apart from tourism. Belonging to the Moroccan migration belt, the Drâa Valley is “exporting” predominantly male workers to other parts of the country. Only a small percentage of workers migrate internationally. What began with young, unmarried men leaving the village seasonally to find work primarily in construction jobs throughout Morocco, has later become a strategy employed by all age groups. Matching the Arab concept of family, the primary goal of these migrant workers is to support their families remaining in the villages. While seasonal labour migration of a small proportion of young male villagers was viewed with suspicion by locals during the 1960s, this practice became common as the village’s socio-economic situation weakened. Consequently, in the past decades migration has become a type of ritual, a “rite of passage” for young males entering manhood. The age at which a youth migrates for the first time – whether to look for labour or for education – depends on the socioeconomic situation of his family, the value his family places upon education, and on his personal aspirations. Hence, youths at the age of thirteen or fourteen all the way up to married men in their sixties migrate for the purpose of ensuring the survival of their families in the village. All of these men keep on as labour migrants throughout their entire working lives (Rademacher 2008b).

Work destinations of migrants

In Ouled Yaoub, three waves of migration between the late 1950s and 2006 can be identified. During the first wave in the late 1950s and 1960s, men left the village only seasonally to spend a couple of months working as farm hands in the northern part of the country. During the 1970s until the 1990s, national migration from Ouled Yaoub expanded because income from agriculture was no longer sufficient to support the extended families – partly because of the drought years between 1973 and 1977 and in the 1980s. Migration during this time was often organized in groups. In the mid 1970s about 20 men, guided by an experienced migrant, went to Casablanca to work in the construction sector. This was also the starting point for international migration when 5 men were recruited to work in France. Further group migrations took place in 1981 to Casablanca, and in 1989 to Goulmim, the gate to the Western Sahara (called Southern Province in Morocco). From the 1980s onwards, increasing numbers of Ouled Yaoub migrants went to the Western Sahara looking for work. This temporary preference was stimulated by the lower cost of living in the South as well as by the South's booming construction sector. The trend, however, has changed over the last few years, because today good job opportunities are rare. In 2006, sixteen out of the twenty migrants went to northern cities such as Casablanca, Rabat, and Marrakech, while only one migrant found work in Smara in the Southern Province. Since the 1980s, the Gulf-Countries and Libya became additional targets for international migration.

The recent migration wave, predominantly characterized by individual migration, began in the 1990s. Stimulated by other migrants, as well as by the difficult situation on the labour market in the Drâa-region, an increasing number of young people quit school ahead of time to seek employment abroad. In the meantime, all age-groups and all families are participating in labour migration.

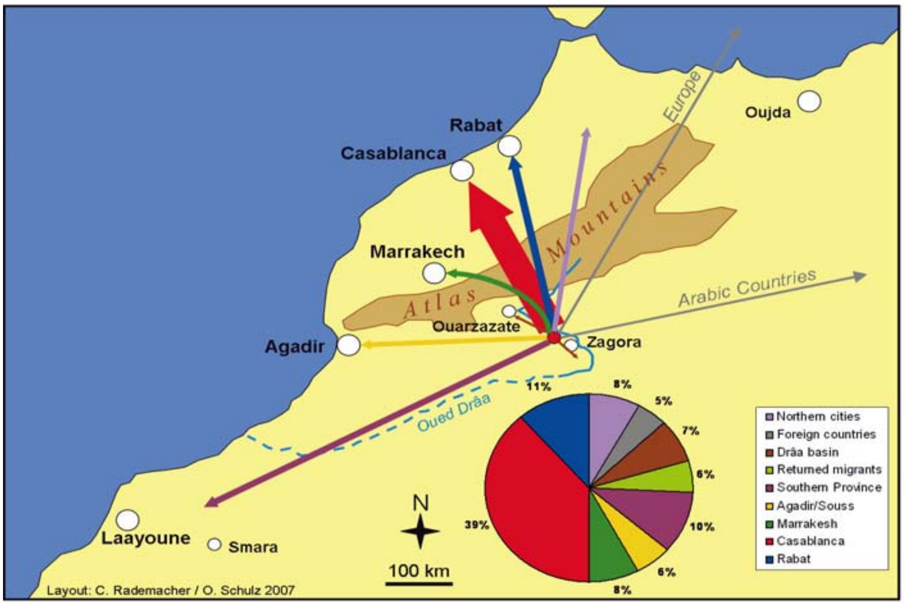

Fig. V.4.1: Destinations of Ouled Yaoub's labour migrants in 2004. (Rademacher 2008a)

Survey data from Ouled Yao show that in 2004 57 % of the migrants found work in construction, 12 % in the service sector, and the rest in various other fields. Most of these migrants were paid modestly (1,250–1,500 DH/month). Only 3 % of migrants found work as civil servants, obtaining a regular and comparatively high salary. Most migrants working on construction sites are highly mobile and follow job opportunities across the country. Consequently, the information given in the map dating from March 2004 (Figure II V.4.1) is highly schematic, and only points out the country's economic centres. That the majority of migrants receive only low wages can be explained by their poor educational background. Even today, dropping out of elementary school after five or six years is common. Many migrants state that the high cost of living in the city prevents most of them from relocating their families to the city. In addition, socio-familial pressures oblige sons to care financially for their aged parents, but most of them are not capable of financing two households. As a result, most families split up (Rademacher 2008a).

International migration from Ouled Yaoub is low (5 %), with some European countries, Saudi-Arabia, and Libya being the primary destinations. A new trend which began around the turn of the century is the (national) migration of entire families. Living together as a family, even under a city's difficult economic conditions, seems to be given preference over being separated or over investing in the non-profitable agriculture of the Drâa Valley. Since 2000, some 15 nuclear families have left the village.

Remittances from national and international migration

The "new economics of labour migration" (NELM) perceives migration as a livelihood strategy to increase and diversify household income, and minimize income risks. Remittances are regarded as the main motivation for migration, for every migrant wishes to improve the living conditions of his household at home via sending remittances (Massey et.al. 1998:17f.). In migration research though, there is no consensus in evaluating the local effects of remittances. Studies in Morocco draw different conclusions with regard to the positive or negative effects of migration and remittances on the local population.

Households in Ouled Yaoub invest remittances to cover basic needs, to renovate or construct houses and furnishing them, for agriculture and livestock breeding, for educational purposes, or for establishing one's own business. People agree that the living standard improved a lot during the last decades due to migration.

A ranking of income sources in a sample of 20 households reveals that 65% of the households regard remittances as the most important income source, while 35% declare migration as the second important source after agriculture or a local fixed salary (e.g. as teacher). 40% of the households named revenues from agriculture – mainly from selling dates – as a second priority, while 20% stated that selling sheep was a third income source. Livestock is mainly sold when households are in financial distress. Only one household is specialised in livestock breeding.

Based on results from a detailed questionnaire, the income sources of households and the different income portions of the total revenue were calculated. In Fig. V.4.2, income sources are divided between households with access to national migration and those with access to international migration.

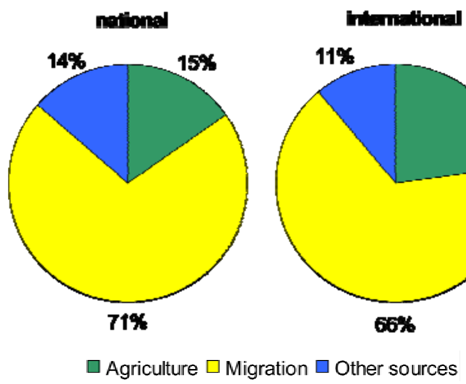

Fig. V.4.2: Income sources from households with access to national and international migration, Ouled Yaoub 2006. Rademacher 2008b.

Besides income from agriculture and migrants' remittances, "other sources of income" which include revenues from livestock sale, fixed salaries, business (shop, trade), and rental income, are listed. Households with access to international migration have a higher total income. In direct comparison, these households show a slight shift in favour of agriculture, because they are able to invest more in this sector and thus gain higher revenues (23% compared to 15% of total income from households with access to national migration only). On closer examination, it is striking that 20% of the households are fully dependent on remittances from migration – most of them stopped practising farming for good. 40% of the households have two sources of income, 30% even three sources. Remittances from international migration are three times higher than remittances from national migration (on average 1350 DH per month). Most national migrants work in low paid jobs, and in the cities often live under precarious conditions where they cannot save any money. Even if they have some savings, their incentive to invest in the rural economy is low. Instead, they prefer investing in the city and settle there permanently. We agree with Kerzazi who states that this process of rural-urban migration can only be stopped if rural regions were developed socially, economically and technically in a fundamental way (Kerzazi 2003: 420f.). What needs to be kept in mind here is the state of the household, i.e. the number of nuclear families living within the household, the number of active family members and the number of migrants, and the fact that investments in education will probably increase household income in the future.

Resource Management

Pastoral management systems – the practise of transhumance

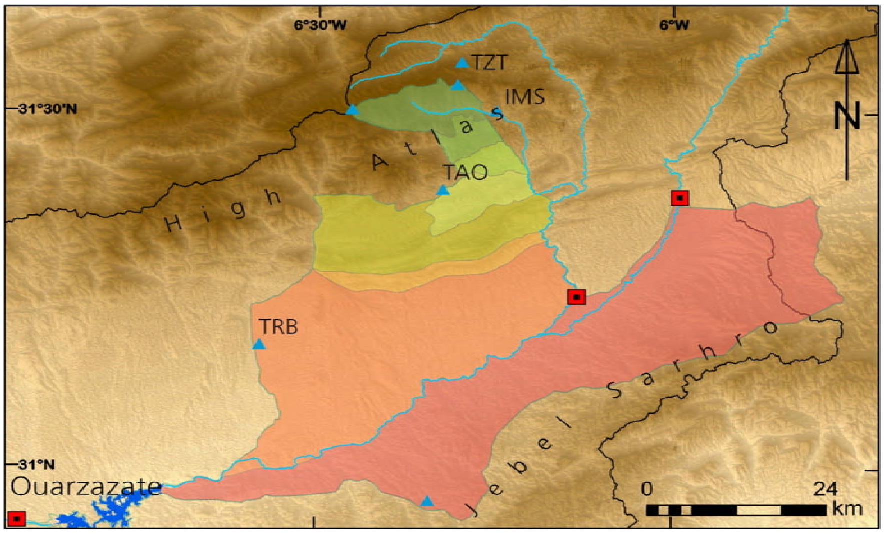

Fig. V.4.3: Pasture areas of the Ait Toumert (from north to south): Awjgal, Asselda, Imaun, Alatagh, Timassinine, Azweg, Imlil and Saghro.

One key area for the study of pastoral management systems was the M'Goun region in the Central High Atlas. This semi-arid environment is characterized by a high climatic variability in space and time. Within this vulnerable environment livestock management includes sedentary as well as mobile transhumant herding practises. Animals of the sedentary population usually stay around the villages or are kept in stables during the winter. The transhumance cycle of the mobile part of the population reaches from mountainous summer pastures at the high ranges of the Atlas to winter grazing areas at the Atlas forelands and the Jebel Saghro. Less than 3 % of the area is irrigated arable land, restricted to the oases. The rest comprises mostly extensively used rangelands and a few fields used for rain-fed agriculture. For all patterns of utilisation, tribal affiliation is the principal key to gaining access to common lands.

Three Berber tribes share the land rights of the M'Goun area: the Ait Zekri, the Ait Toumert and the Ait Mgoun. From west to east, they occupy neighbouring strips of land. This territorial design follows a "transhumant logic", combining grazing lands with divergent environmental characteristics. In the following, the strategies and mobility decisions of the mobile fraction of the Ait Toumert are analysed. The grazing area of the Ait Toumert is collective land which includes pastures solely used during spring, autumn and summer in the north, and the winter pastures in the south. The pasture areas used exclusively by the Ait Toumert are the summer and intermediate pastures in the high mountains. The mountainous summer pasture area of the Ait Toumert is called Awjgal (see Fig. V.4.3). The intermediate pastures of Asselda and Imaun are used by the Ait Toumert in springtime and during autumn. Near winter pastures are located at the foot of the mountains in Alatagh, Timassinine and Azweg. The basin of the Oued Dadès is divided into two pasture areas: Imlil in the north of the Oued and Saghro in the south of the river fading into the Jebel Saghro. These two grazing areas are the far winter pastures. While the summer pastures are exclusively used by the Ait Toumert, the winter pastures are shared by the neighbouring fractions of the Ait Zkri (west) and Ait Mgoun (east) and other groups from the south. During winter, the three groups can move to every pasture they desire, though *de facto* the majority stay as near as possible to their summer pastures. An important factor of the collective land tenure is the traditional *agdal* institution which is a common instrument to protect the forage plants. "An agdal is a communal pasture whose opening and closing dates are fixed by the community of users. An agdal is a collective property used by tribal and intertribal groups: customary laws limit its boundaries and fix its closing and opening dates." (Ilahiane 1999:24) Within the grazing area of the Ait Toumert, the *agdal* refers to the summer pasture of Awjgal.

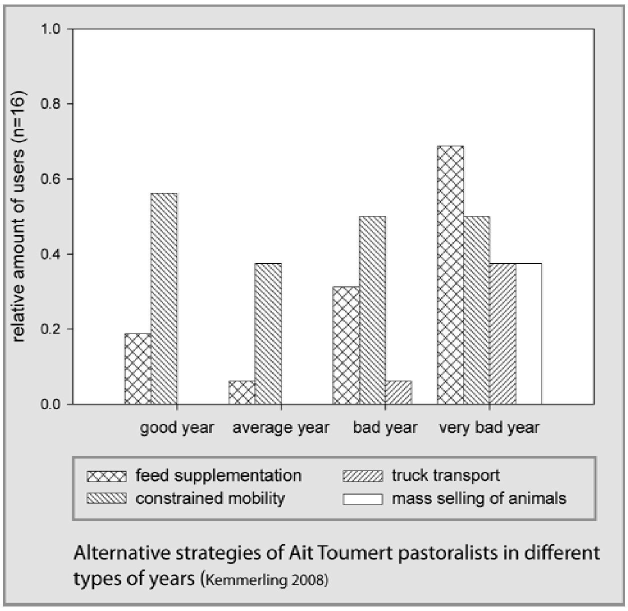

Fig. V.4.4: Management decisions of Ait Toumert nomads).

<u>The importance of local knowledge</u>

Anthropologists are interested in the emic perspective on culture and in the local knowledge which enables local communities to adapt to variable environments. Within this context, local environmental knowledge is a key factor to understand the pastoral-nomadic peculiarities of culture and pastoral strategies for a sustainable range management. The local knowledge of climatic variability and the availability of fodder plants as well as social networks of herders are the background against which herd management decisions are made. Pastoral-nomadic groups like the Ait Toumert must have a profound environmental knowledge in order to minimize risks due to the unreliable precipitation and variable access to forage plants. Therefore, an investigation of cognitive structures underlying decision making processes can help to understand the pastoral-nomadic exposure to natural resources.

Understanding the transhumance system of the Ait Toumert requires to emphasize the diverse range management strategies actually used by pastoral nomads. This includes the spatial and temporal differentiation of mobility patterns on the one hand and the utilization of alternative management strategies on the other. The standard or normative transhumance cycle runs from the summer pastures in the High Atlas Mountains to the winter pastures in the basin of Ouarzazate. Every Ait Toumert who was questioned about his mobility pattern described exactly this standardized transhumance cycle. Deviations of this norm did not become apparent until informants were asked in detail where and when they have been in the last years. It soon became evident that deviations from the normative cycle are more frequent than the obedience to the norm.

The local perception of a year's quality mainly depends on rainfall stochastic in the different pasture areas. Range management has to be adapted to unpredictable environmental conditions. In general, the key strategy of reacting to variability in natural resources is mobility. For different types of years pastoral nomads choose various mobility patterns and specific actions from a set of alternative strategies appropriate to the year's quality.

All pastoral nomads move to the summer pasture with the opening of the *agdal*, generally in mid-May until September. Equally all pastoralists are passing the intermediate ranges of Asselda, Imaun, Alatagh and Timassinine between the summer and winter months. The mobility pattern from March/April to September can be regarded as fixed. During the winter months however, mobility patterns deviate more often from the norm. The full normative transhumant cycle, where herders spend the months between November and February at the Atlas forelands in Imlil and the Saghro, is only practised in good and very good years. Especially for dry years, pastoral nomads apply a set of risk minimizing strategies. These include buying extra fodder during the winter time, often combined with the decision for a reduced or constrained mobility in bad years. Buying extra fodder has meanwhile become very common even in normal years, allowing the pastoralists to avoid extensive movements and to keep the herd size high. Truck transport to remote pasture areas is another strategy sometimes followed, though only by wealthier families because a certain herd-size and capital is needed to make it profitable. Mass selling of animals often is the last chance to avoid a total loss in very bad years.

Conclusions

In our article we highlighted the role of labor migration and local knowledge on the management of natural resources. Nowadays in the Drâa valley in southern Morocco, remittances from migrants are essential to sustain a decent livelihood. Due to erratic water availability caused by negative effects of the high climatic variability, droughts and management problems of the Mansour Eddahbi Dam, income from agriculture has become less and less reliable. In the mountainous areas of the northern Drâa catchments, where pastoral nomadism is still practiced as an additional income generating strategy, profound local knowledge about management options is essential to cope with environmental constraints. But even in this climatically privileged region, labor migration is important and practiced by family members in sedentary and mobile populations. Today national and international migration influence socio-economic development and the demographic dynamics of the whole working area. The income generated by migrants influences management strategies and the sustainability of pasture, land, and water-use by allowing additional capital to be invested in the agricultural sector. Migrant remittances can be regarded as an additional buffer, cushioning the impact of climatic constraints on the livelihood of the local populations.

Nevertheless, this research has clearly demonstrated that labor migration does not only depend on economic factors but also on a complex bundle of motives. The personal decision to migrate depends on several factors and varies from person to person. Although economic reasons are always mentioned, social factors such as social positioning within the hierarchical social system of the village or family crisis are sometimes also dominant motives. Additionally, in areas with a long tradition of migration, such as our case of the village of Ouled Yaoub, the existence of migrant networks facilitates migration. Thus, migration becomes part of men's life cycles.

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