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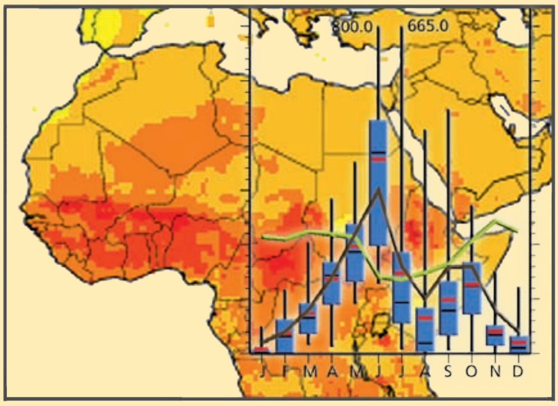
IMPETUS Atlas
Benin

Research Results 2000 – 2007



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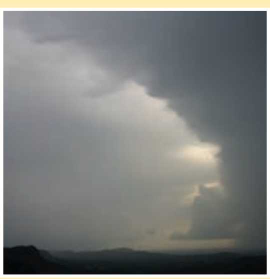

Universität zu Köln

Ministry of Innovation, Science, Research and Technology of the German State of North Rhine-Westphalia

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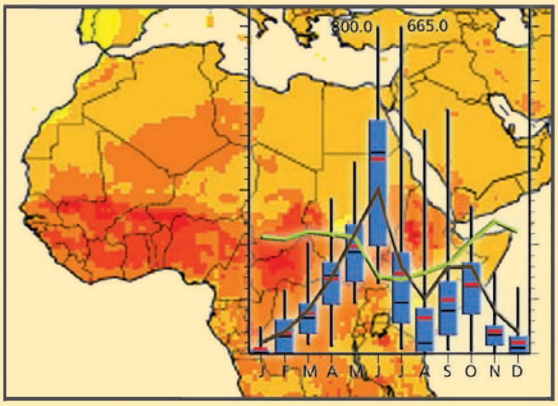

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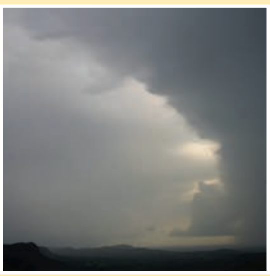

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IMPETUS Atlas Benin

Research Results 2000 – 2007

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Preface

Within the IMPETUS-Project, many valuable data, comprehensive analyses, and relevant model results related to the fresh water cycle and other associated topics have been compiled. It is the concern of the project to communicate those scientific results in an easy and comprehensible manner to national and local administrations, development agencies, the broader scientific community, and other interested people.

The IMPETUS Atlas is an appropriate approach to overcome the gap between scientists and stakeholders, as it can be used as a sound database and a basis for comprehensive discussion in all situations related to the involved topics. In addition, it should demonstrate the extensive and interdisciplinary research of IMPETUS during the last seven years. To ensure the reliability of the atlas, each contribution was peer reviewed by two experienced project members. For each of the two study areas in Morocco and Benin, a separate atlas was prepared.

The individual contributions of this atlas would never have been possible without the help of many institutions and colleagues, which shared their data and experience. We especially thank the Direction Général de l'Eau, the Institut National de la Statistique et de l'Analyse Economique, the Institut de Recherche pour le Développement, Service Météorologique National and many others. We also thank the student workers Tim Breuer, Ulla Kutsch, Dominique Kohn, Philipp Aben and Arthur Rachowka, who have done a great job during the layout and map making process. Volker Ermert proofread the whole atlas and Tim Brücher, Ralf Hoffmann, Patrick Ludwig, Simone Kotthaus, Andreas Krüger and Melanie K. Karremann parts, for which we thank them explicitly.

The content of the atlas is divided into several chapters that reflect the different spatial scales and diverse topics of the research. The many links between the different contributions are indicated by a cross-reference (↗) directing the reader to the number of another contribution.

A multitude of scientific papers and PhD-Theses emerged during the last years. Most of the PhD-Theses are electronically published and can be accessed at the homepage of the libraries: `http://hss.ulb.uni-bonn.de/diss_online/` or `http://kups.ub.uni-koeln.de`. Other results of the IMPETUS project not summarized in this atlas can be found at the project homepage `http://www.impetus.uni-koeln.de`.

The maps of this atlas will be made available digitally by the use of the “Interactive IMPETUS Digital Atlas”, which will be published soon after the release of this printed edition (`http://www.impetus.uni-koeln.de/iida`). New capabilities will complete and extend the printed version; e.g., the magnification, custom map creation and information retrieval from the map data.

In the name of all project members and contributors, the editors feel confident that the atlas can be used as a valuable tool to share and communicate new research results and to facilitate communication and that it serves as a reference for the applied topics.

This third edition is mainly a reprint of the second edition with some minor corrections.

Michael Judex
Hans-Peter Thamm

Content

Introduction

1 IMPETUS – An Integrated Approach to the Efficient Management of Scarce Water Resources in West Africa ____ 3
Andreas Fink, Barbara Reichert and Michael Christoph, IMPETUS Chair

2 Benin – Socio-Enconomic Background ____ 5
Moritz Heldmann, Valens Mulindabigwi, Tim Breuer

3 The Upper Ouémé Catchment ____ 7
Mulindabigwi, Hadjer, Giertz, Klein, Heldmann, Judex

Climate – Current Conditions and Impacts of Climate Change

4 Rainfall Variability in West Africa ____ 11
Andreas H. Fink, Simone Kotthaus and Susan Pohle

5 Human Activity and Future Climate Change ____ 13
Heiko Paeth, Kai Born and Kai Oliver Heuer

6 Impact of Climate Change on Malaria Risk in West Africa ____ 15
Volker Ermert, Andreas H. Fink, Andrew P. Morse, Anne E. Jones and Heiko Paeth

7 The Climate of Benin (1961 to 1990) ____ 17
Volker Ermert and Tim Brücher

8 Observations of Past and Present Rainfall in Benin ____ 19
Malte Diederich and Clemens Simmer

9 Spatial and Temporal Rainfall Climatologies of Benin ____ 21
Andreas H. Fink, Susan Pohle and Ralf Hoffmann

10 Changes in Benin's Monsoon Climate ____ 23
Heiko Paeth, Kai Born and Kai Oliver Heuer

11 Scenarios of the Regional to Local Rainfall Variability ____ 25
Andreas Krüger and Kai Born

Water Availablility, Water Consumption and Health

12 Gauged Sub-Catchments of the Ouémé River ____ 29
Simone Giertz

13 The Hydro-Meteorological Network of the HVO ____ 31
Andreas Fink and Simone Giertz

14 Observation Points for Hydrochemistry and Piezometry in the Ouémé Catchment ____ 33
Antoine Kocher and Tobias El-Fahem

15 Hydrologic Modelling in the Ouémé Catchment at Local and Regional Scales ____ 35
Simone Giertz and Gero Steup

16 Assessing the Impact of Climate and Land Use Change on Future Water Availability in the Ouémé Catchment 37
Simone Giertz

17 Acquiring a Database for Hydrological Process Analysis in the Aguima Catchment 39
Simone Giertz and Gero Steup

18 Analysing the Effects of Land Use/Land Cover Changes on the Water Cycle 41
Simone Giertz and Gero Steup

19 Drinking Water Supply in Benin 43
Moritz Heldmann and Martin Doevenspeck

20 Drinking Water Supply in the Upper Ouémé Catchment 45
Farouk Mazou, Alexandra Uesbeck and Rainer Baginski

21 Bacteriologic Analysis of Drinking Water Sources in the Upper Ouémé Catchment 47
Alexandra Uesbeck, Rainer Baginski and Farouk Mazou

22 Viral Contamination of Drinking Water Sources 49
Jens Verheyen and Herbert Pfister

23 Water and Health 51
Thamar Klein

24 Regional Survey: Economic Dependence on Water 53
Kerstin Hadjer

25 Water Consumption Embedded in its Social Context 55
Kerstin Hadjer, Thamar Klein and Michael Schopp

26 Water Demand at the Household Level in Benin 57
Marion Schopp and E. Adams

Geology, Geomorphology and Soils

27 Soil Map of Benin 61
Simone Giertz and Claudia Hiepe

28 Geomorphology in Benin 63
Simone Giertz and Sarah Schönbrodt

29 Geology of the Ouémé Catchment 65
Tobias El-Fahem and Antoine Kocher

30 Soil Map of the Upper Ouémé Catchment 67
Claudia Hiepe and Simone Giertz

31 Erosion Modelling in the Upper Ouémé Satchment - Status Quo 69
Claudia Hiepe

32 Erosion Modelling in the Upper Ouémé Catchment - Scenario Analysis 71
Claudia Hiepe

33 Soil Distribution in the Aguima Catchment 73
Claudia Hiepe and Birte Junge

34 Soil Erosion in the Aguima Catchment 75
Claudia Hiepe and Birte Junge

35 Hydrological Processes and Soil Distribution in the Ara Catchment ____ 77
Gero Steup

Land Use and Land Cover

36 Land Use in the Ouémé Catchment ____ 81
Hans-Peter Thamm and Michael Judex

37 Satellite Imagery of the Upper Ouémé ____ 83
Michael Judex and Hans-Peter Thamm

38 Land Use and Land Cover in Central Benin ____ 85
Michael Judex, Hans-Peter Thamm and Gunter Menz

39 Land Use Dynamics in Central Benin ____ 87
Michael Judex, Hans-Peter Thamm and Gunter Menz

40 Modelling Scenarios of Land Use Change ____ 89
Michael Judex

41 Application of a "Low Cost" Ultra Light Air Vehicle for Spatial High Resolution Remote Sensing ____ 91
Hans Peter Thamm

42 Vegetation Trends in Benin (1982–2003) ____ 93
Julia Röhrig

43 Natural Agricultural Marginality in Benin ____ 95
Julia Röhrig, Claudia Hiepe and Malte Diederich

44 Bushfire in Benin ____ 97
Hans-Peter Thamm

45 Survey of Inland Valleys in the Upper Ouémé Catchment ____ 99
Simone Giertz, Gero Steup, Luc Sintondji, Felix Gbaguidi and Sarah Schönbrodt

Society and Economy – Insights into Complex Patterns

46 Demography: Spatial Disparities and High Growth Rates ____ 103
Moritz Heldmann and Martin Doevenspeck

47 Population Projections for Benin until 2025 ____ 105
Moritz Heldmann and Martin Doevenspeck

48 Religion in Benin ____ 107
Kerstin Hadjer and Moritz Heldmann

49 Ethnic Groups in Benin ____ 109
Moritz Heldmann

50 Illiteracy and School Attendance ____ 111
Moritz Heldmann and Martin Doevenspeck

51 Settlement Dynamics in Central Benin ____ 113
Martin Doevenspeck and Uwe Singer

52 Regional Survey on Livelihood Security ____ 115
Kerstin Hadjer, Thamar Klein and Uwe Singer

53 Central Issues of Social and Economic Behavior 117
Kerstin Hadjer

54 Occultism and its Impacts on Economic Behaviour 119
Kerstin Hadjer

55 Land Property Rights in the HVO 121
Moritz Heldman, Kerstin Hadjer and Valens Mulindabigwi

56 Land Use Rights: Migrants and Foreign Cattle Herders 123
Valens Mulindabigwi, Moritz Heldmann and Kerstin Hadjer

57 Livestock Husbandry in Benin and Resource Use 125
Ina Gruber

58 Level and Formation of Farmland Prices in Benin 127
Armin Kuhn, Mousseratou Saliou, Ina Gruber and Jean Adanguidi

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Fishermen on *Lac Nokué*

Introduction

1 IMPETUS – An Integrated Approach to the Efficient Management of Scarce Water Resources in West Africa

Andreas Fink, Barbara Reichert and Michael Christoph (IMPETUS Chair)

The availability of fresh water is a fundamental condition for human life and one of the biggest challenges for the next decades, especially in Africa. In order to solve present and possible future problems with regard to fresh water supply, a clearly interdisciplinary and holistic approach is needed, involving natural, socio-economic, and health sciences.

For West and Northwest Africa, the IMPETUS initiative – a joint venture of the Universities of Cologne and Bonn, Germany – follows such an integrated approach for two representative river catchments. The Wadi Drâa in south-eastern Morocco and the Ouémé River in Benin (Fig. 1) were chosen for their feasible size (< 100,000 km²), availability of pre-existing data sets, politically stable conditions, relevance, and representativeness. The Drâa catchment in the southeast of Morocco is typical of a gradient from semi-arid subtropical mountains to their arid foothills; the Ouémé basin in Benin is typical of a wet to dry sub-humid climate of the outer tropics. The Ouémé River drains about half of the country of Benin, whereas the Wadi Drâa is the most important river flowing from the Atlas mountain chains towards the Sahara.

Sustainable water management requires reliable data and projections for regional planning and political decision makers. A comprehensive diagnosis of the water cycle was carried out during the first project phase (2000–2003). In the second phase (2003–2006), qualitative and quantitative models were adapted or newly developed for both regions. Projections of future developments were derived from scenario calculations, process understanding, and from expert knowledge. In the last project phase (2006–2009), Spatial Decision Support and Information Systems (SDSS/IS), as well as Monitoring Tools (MT), have been developed within a set of multi-disciplinary "problem clusters". A variety of problem clusters were defined to handle complex problems for which no single solution exists in an adequate manner. The problem clusters are meta-problems that require a multi-disciplinary analysis in order to draw conclusions with respect to future developments. Problems clusters are grouped under four thematic domains: food security, hydrology, land use, and society and health.

The SDSS/IS and MT systems developed in the problem clusters are available online at http://www.isdss.de. However, many more pertinent results for the study regions in Benin and Morocco were achieved within the IMPETUS project. The publication of the print version of this atlas and its digital amendment (http://www.impetus.uni-koeln.de/iida) is intended to make these results widely available to interested scientists, regional administrations, and the public. The present atlas provides insight into the diversity of the analyzed influence factors and problems dealing with the topic of fresh water. It presents some of the most important research results achieved for various spatial and temporal scales. Thematic maps and additional explanations allow for the accessibility of water-related information to a wide audience.

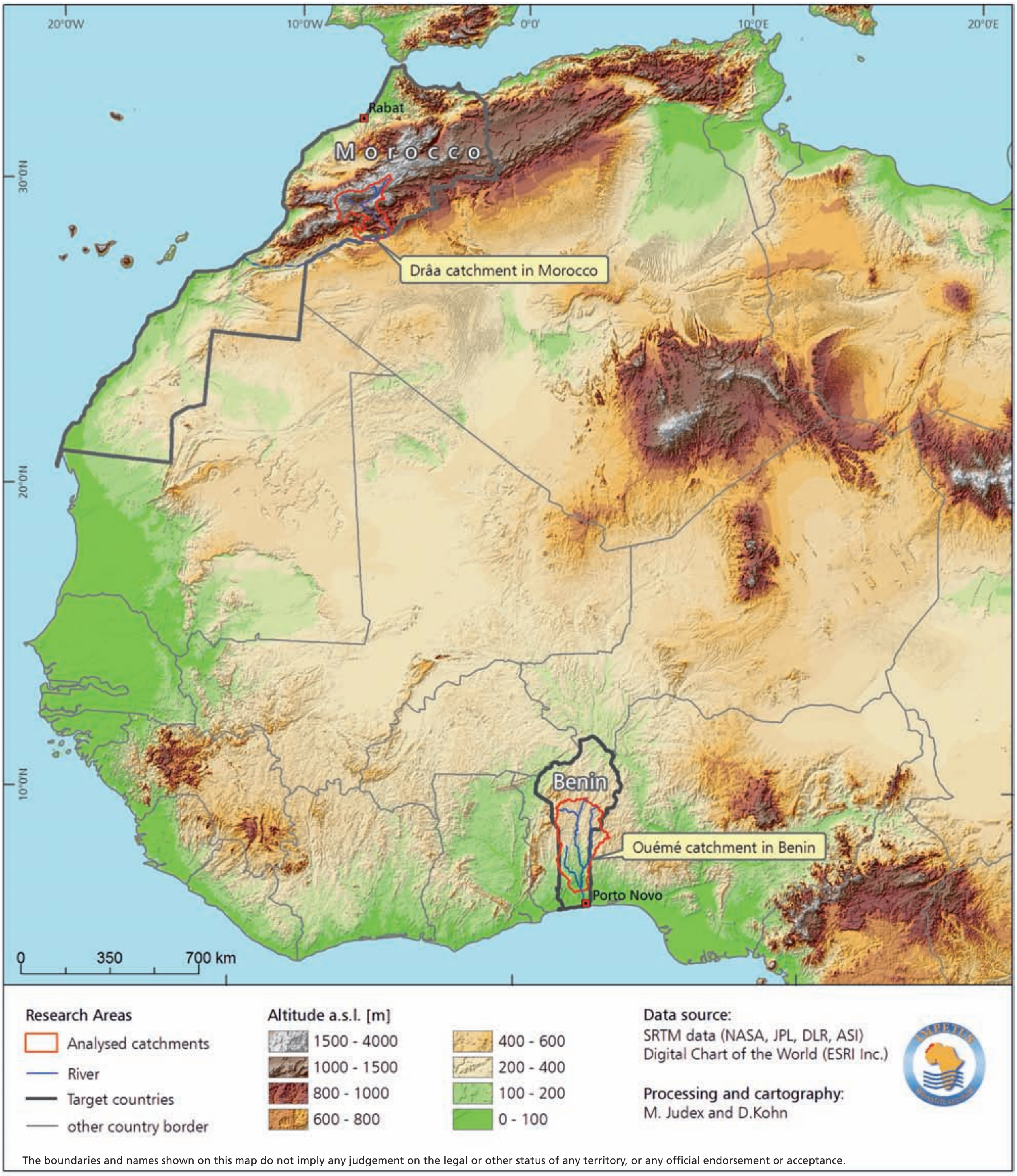

Fig. 1: *Studied river catchments in West Africa*

2 Benin – Socio-Economic Background

Moritz Heldmann, Valens Mulindabigwi and Tim Breuer

Benin is located on the Guinea Coast of West Africa (between 6° 25′ and 12° 30′ North latitude and 0° 45′ and 4° East longitude) and is bordered to the west by Togo, to the east by Nigeria, and to the north by Niger and Burkina Faso. It stretches 670 kilometres from the Bight of Benin in the south to the Niger River in the north and has a coastline stretching 122 km from east to west.

History and Population

Official Name	Republic of Benin (République du Bénin)
since 1990	Republic, parliamentary presidential system
1975–1990	Socialist Period
1960	Independence
Population	2002: 6,769,914 (Census); 2008: 8,009,445 (IMPETUS estimation)
Ethnicities	59 (2002) Census
Languages	French (official) over 50 African languages, major vehicular languages: Fon, Yoruba, Dendi, Bariba
Religions	Christianity, Islam, Vodoun and other traditional religions

After independence from French colonial rule, the country was called "Republic of Dahomey" with reference to the pre-colonial "Kingdom of Danhomè" that had prospered in South-Benin until the conquest of the French in 1892. In 1975, former President Kérékou changed this name into the more impartial "Benin", which was a historical kingdom located in neighboring Nigeria.

Regional Structure

Since the decentralization reforms in 2002, Benin has been subdivided into 12 administrative regions called *Départements* (instead of only 6 beforehand), which represent the national government on the regional level (Fig. 1). Each Département is headed by a prefect assigned by the central government. On a lower level, the former Sous-Préfectures have been promoted to 77 financially independent area-municipalities called *Communes*, which represent the local population through regularly elected municipal councils headed by mayors.

Capital	Porto Novo (official capital), Cotonou is the economic capital and the seat of government
12 Départements	Local structures of the Central/National State:
77 Communes	Decentralized territorial units, area municipalities. Subdivided into 546 Arrondissements

Economy and Development

GDP	5.5 Billion US $ (2007[1]) (Agriculture: 37.1 %, Industries: 14.5 %, Services: 48.4 %)[1]
Real GDP growth	5.0 %[1]
GDP per Capita	1,141 US $ (measured by purchasing power parity, PPP, income)[2]
Human Development Index	RANK 163 of 177, (value 0.437, data from 2005)[2]

[1]EIU, 2008
[2]UNDP, 2007

Benin's economy is based on agriculture, trading, and transit. The most important commercial crop and export product is cotton, accounting for up to 16.7% of the GDP in 2006 (EIU, 2008), followed by other crops such as cashew, shea-butter, palm oil, and pineapples. China is by far the biggest trade partner. Benin predominantly imports foodstuffs, capital goods, and petroleum products. Besides official economic indicators, the informal sector and transit to neighboring countries play a major role in the country's economy. The UNDP Human Development Index, which measures health care, education, and standard of living, ranks Benin at 163rd out of 177 countries (UNDP, 2007). Benin is thus classified as one of the Least Developed Countries (LDC).

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Fig: 1: *Administrative map of Benin*

3 The Upper Ouémé Catchment

Valens Mulindabigwi, Simone Giertz, Kerstin Hadjer, Moritz Heldmann and Michael Judex

The upper Ouémé catchment (HVO: Haute Vallée de l'Ouémé) is located in central Benin (9° – 10° N and 1° 30' – 2° 45' E) in the departments of Donga and Borgou and covers an area of 14,366 km² (Fig. 1). It contains about 400,000 inhabitants and at least 35 ethnic groups, and the main languages are Bariba, Yom, Lokpa, and Yorouba.

Basic facts

The Upper Ouémé catchment is located in central Benin.

- Total area 14,366 km²
- Area under protection (*Forêt classée*) 2,420 km²
- Road length (paved) ca. 320 km

Natural environment

Climate: Unimodal rainy season from about May to October.

- Precipitation (Ø Parakou station): 1,150 mm
- Temperature (Ø Parakou station): 26.8 °C

Vegetation: The natural vegetation is a mosaic of woody savannas and small forest islands. Tree density varies between near zero and 70%. Some azonal vegetation units are found at special locations (e. g., inland valleys, gallery forest or inselbergs).

Soils: Major soil type is a *sol ferrugieux tropicaux*.

Geomorphology: The landscape is a peneplain with isolated inselbergs.

- Highest point (Inselberg Soubakperou) 620 m a.s.l.
- Lowest point (Ouémé) 230 m a.s.l.

Geology: Major rock types in the Precambrian crystalline basement (Dahomeyides) are migmatites.

Hydrogeology: The region is characterized by a fractured bedrock aquifer at the bottom and a regolith aquifer in its weathering zone at the top.

Hydrology: Caused by the unimodal rainy season, the discharge dynamic is characterized by high flow during the rainy season. From December to May nearly all rivers dry out.

- Drainage density: 0.78 km/km²
- Mean discharge Ouémé Betérou rainy season (September) in the measuring period 1952–2002: 249 m³/s
- Maximal peak discharge in the measuring period 1952–2002: 787 m³/s (1963)

Administrative structure

The *Communes* Parakou, Tchaourou, and N'Dali in Borgou and the *Communes* Bassila, Copargo, and Djougou in Donga cover the main part of this catchment. Although the *Communes* have been autonomous territorial units responsible for the local development since the decentralization reforms in 2002, planning and realization of development projects is difficult due to insufficient budgets and partly technical competence.

Migration and demographics

Because of a low demographic density (28 inhabitants / km²) and agriculturally favorable climate conditions, the population of this area is rapidly growing (4 % per year) compared to the national average growth (3.25 %). This high growth rate is the consequence of agricultural colonization by migrants coming from different parts of the country.

Economy and Development

The economy of the upper Ouémé catchment is mainly based on agriculture and trade (Tab. 1). The principal export products are cotton, cashews, and shea nuts (*Vitellaria paradoxa*). The *Commune* Tchaourou is the largest producer of cashew nuts in Benin, with an annual production of about 4000–5000 t / year. Although maize, manioc, groundnuts, and rice are generally not exported, they are important products for the rural income.

Several processing units are located in the region, including a textile factory (COTEB) and two cotton factories in Parakou, a cashew nuts factory in Tchaourou, and a brewery (SOBEBRA) and an ex-

Tab. 1: *Economic activities in the* Communes *of upper Ouémé catchment and Ouaké.*

Economic Activities	men	women	total
Agriculture and Forestry	396	163	559
Craft and Industry	65	126	191
Services	96	292	388
Total	557	581	1138

Source: Statistically representative survey, 2004 (n=790)

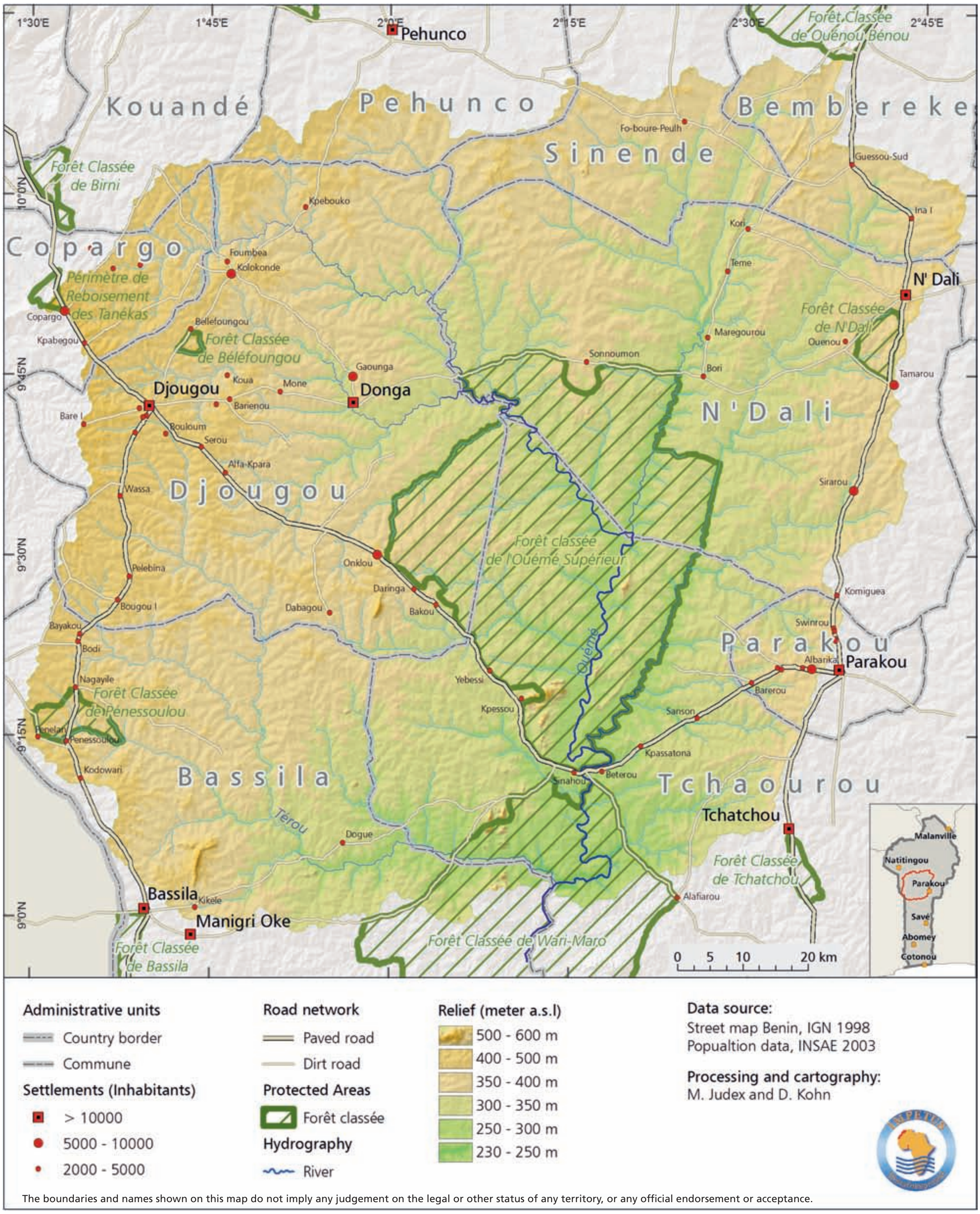

***Fig. 1:** Map of the Upper Ouémé catchment in Benin*

port company for karité nuts in Parakou. The upper Ouémé catchment has great development potential due to its geographic position, the presence of the cities Parakou and Djougou, and especially because of its road infrastructure connecting the commercial centers to the neighboring countries. Moreover, the current projects to build an international airport and an inland port in Parakou are advantageous for economic growth.

Storm clouds near Parakou.

Climate – Current Conditions and Impacts of Climate Change

4

Rainfall Variability in West Africa

Andreas H. Fink, Simone Kotthaus and Susan Pohle

The climate of Sub-Saharan West Africa experienced a large variability during the last several decades, often exceeding those anywhere on earth. Distinct trends and decadal variability can be identified within the three climate regions of the West Sahel, the Central Sahel, and the Guinea Coast. One striking features pertains to the overall drier conditions in the entire study region since the 1970s, even though the Sahel exhibits an upward trend recently.

Introduction

West African rainfall stations (Fig. 1) within the regions of the West Sahel (7 stations), the Central Sahel (14 stations), and the Guinea Coast (16 stations) have been found to exhibit similar rainfall variability on inter-annual to decadal time scales (Nicholson and Palao, 1993; Moron, 1994). In order to analyze the variability of rainfall of these regions, the June to September standardized rainfall anomalies from 1921 to 2007 have been calculated and are shown in Fig. 2. Due to the collaboration with the African pan-national organizations AGRYHMET and ACMAD, the present precipitation index time series are based on a nearly constant database (Fig. 2, black curves).

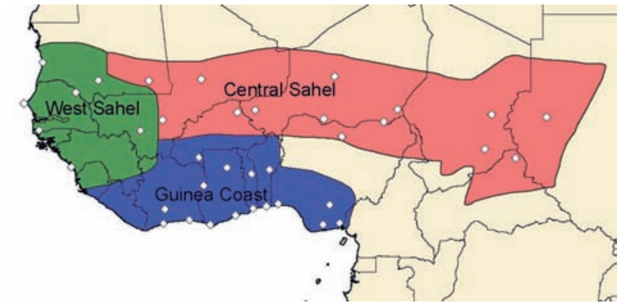

Fig. 1: *The three regions in West Africa including the locations of the rainfall stations.*

Method

The standardized June-to-September rainfall anomaly $index_j(i)$ for a station j in a given year i is calculated by dividing the observed June-to-September rainfall anomaly with respect to the mean of the base period 1950–1990 by the base period's standard deviation $\overline{x}_j$,

$$index_j(i) = \frac{X_j(i) - \overline{X}_j(1950-1990)}{\sigma_j(1950-1990)}$$

$$\sigma_j(1950-1990) = \sqrt{\frac{\sum_{k=1950}^{1990}\left(X_j(k) - \overline{X}_j\right)^2}{N_j - 1}}$$

where N_j is the number of available years at a station j. The $index_j(i)$ is not computed if the rainfall amount of at least one month from June to September is missing. The regional indices are the averages over all available stations n_j in the year i.

$$index_{West\ African\ Region}(i) = \frac{\sum_j index_j(i)}{n_j}$$

Results

The rainfall climate of Sub-Saharan West Africa clearly varies over the study period. It is well known that this area is affected by trends and decadal variability in rainfall, which have been far greater in this region in recent years compared to other places on earth.

The two Sahelian regions (Fig. 2a) experienced a multi-decadal wet episode between 1930 and 1970, which was only temporarily interrupted by a few anomalously dry years in the 1940s causing a secondary minimum of the 11-year running mean. A multi-decadal dry episode commenced in the early 1970s with notable drought periods in the early 1970s and mid-1980s. In the two Sahelian zones, the last 17 years since 1990 are characterized by a return to near-normal rainfall conditions, as indicated by the 11-year running mean curves that approach the zero line in Fig. 2a. The latter especially applies to the Central Sahel where two particularly wet years were observed, in 1999 and 2003. Even though year-to-year rainfall variability is higher in the more densely populated coastal areas, it is evident that sequences of dry years dominated the first half of the past century, and have been prevailing since the 1970s (Fig. 2b). The only prominent wet decade at the Guinea Coast was the 1960s, during which four out of a total of five years occurred in which one positive standard deviation was exceeded.

It is notable that the occurrence of so-called dipole-years (e.g. 1958, 1999 and 2003), characterized by anomalously dry (wet) conditions in the Sahel regions, was accompanied by positive (negative) anomalies at the Guinea Coast. However, these di-

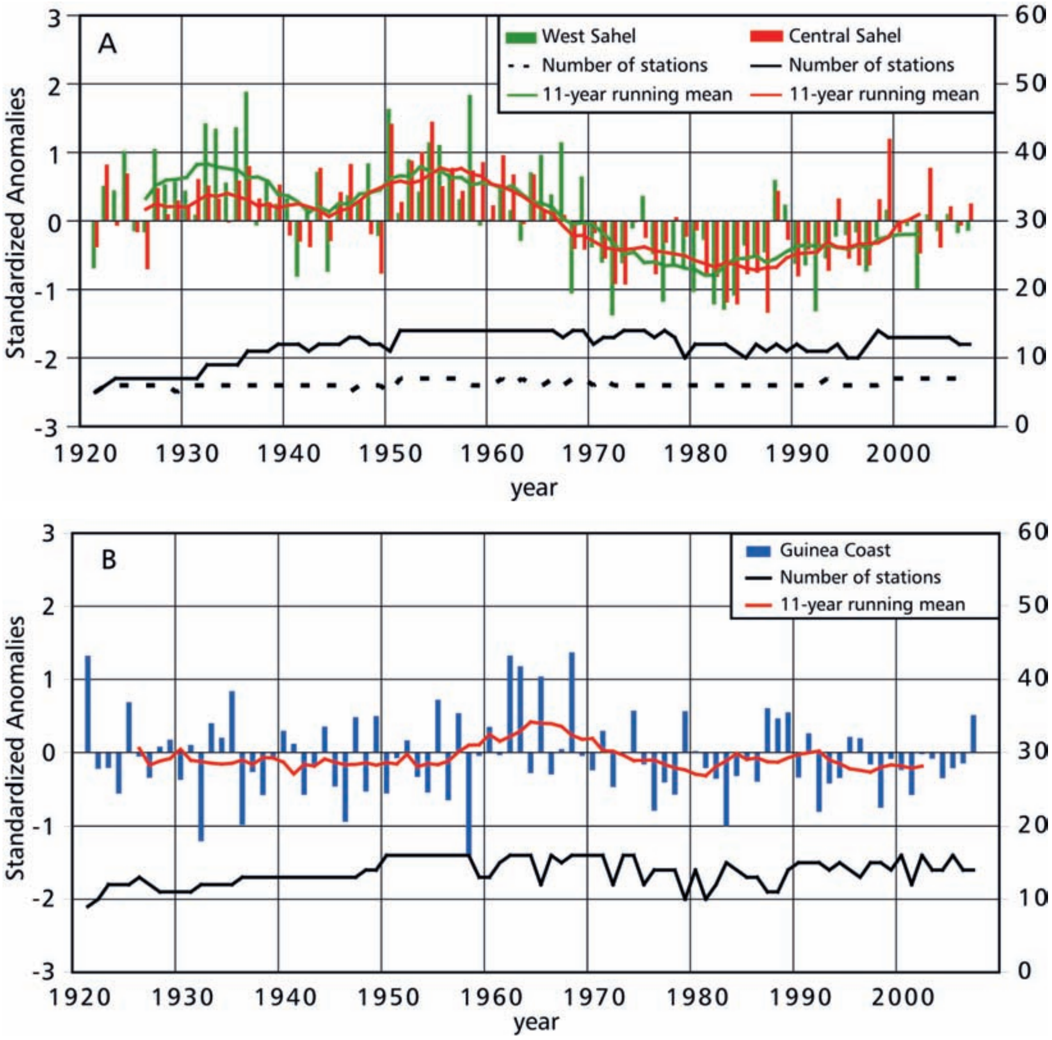

__Fig. 2:__ Standardized precipitation anomalies with regard to 1921–2006 for (A) Central and West Sahel and (B) Guinea Coast.

pole criteria, suggesting an anomalous latitudinal position of the rain-bearing Intertropical Convergence Zone (ITCZ), are satisfied in approximately as many years as wet or dry conditions prevail over all of West Africa.

The large natural variability and the prospects of an accelerating anthropogenic climate change due surface changes endanger the possibility of sustainable development in West African countries, in which the agricultural sector comprises up to 80 % of the economy. Therefore, the climate research community strives for skilful forecasts of the West African monsoon rainfall ranging from weeks to decades. Clearly, this will require interdisciplinary methods and inputs from various scientific disciplines, an approach pursued in IMPETUS.

Acknowledgements

Data until 1998 have been kindly provided by Dr. Landsea from NOAA/AOML/HRD in Miami and have been updated by the authors using CLIMAT and SYNOP messages. Data to fill in gaps between 1999 and 2007 have been furnished by A. Kamga and Athanase Bizimama from ACMAD (Niamey, Niger) and Abou Amani from AGRHYMET (Niamey, Niger).

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5 Human Activity and Future Climate Change

Heiko Paeth, Kai Born and Kai Oliver Heuer

Apart from increasing greenhouse gas concentrations, the changes in land cover imposed by human activities such as deforestation, agriculture, and pasturing play a crucial role in the African climate. A new set of climate change projections, with a high-resolution regional climate model, allows for the assessment of the regional perspective of the future African climate under realistic forcing conditions.

Model simulations

The regional climate model REMO has been implemented over tropical and northern Africa to account for atmospheric processes at the synoptic scale that are not resolved by global climate models. The objective is to provide regional patterns of interannual variability and total change of climate, which meet the requirements by governments at the national and regional level. To date, REMO has been found to reproduce the observed characteristics of African climate in a reliable manner (Paeth et al., 2005).

Assessing future climate change implies that realistic estimates of future human activities are made. For simulations with REMO increasing greenhouse gas concentrations are taken from the IPCC scenarios A1B and B1 (Nakicenovic and Swart, 2000) to evaluate the effect of mitigation policy on the future African climate. In addition, the process of land degradation has been taken into account by prescribing anthropogenic changes in albedo, forest, and vegetation cover. These changes are calculated based on estimates of future population growth in Africa (UN, 2006) and resulting deforestation rates (FAO, 2006). Long-term ensemble simulations with REMO capture the transient climate changes between 1960 and 2050, and allow for the quantification of climate change signals against the background of internal variability.

Results

The projected changes in land cover for Benin are depicted in Fig. 1. The assumption is that land cover changes primarily take place in the savannah and dense woodlands, by transforming these areas to fields and grassland; urbanization is also taken into account. Further, the process of desertification is modelled in the southern Sahel zone.

The changes in annual precipitation and near-surface temperature, resulting from the combined influence of enhanced greenhouse conditions and land degradation, are shown in Fig. 2. The panels indicate ensemble-mean values, which are a measure of the climate change signal, expressed as linear trends for the period from 2001 to 2050.

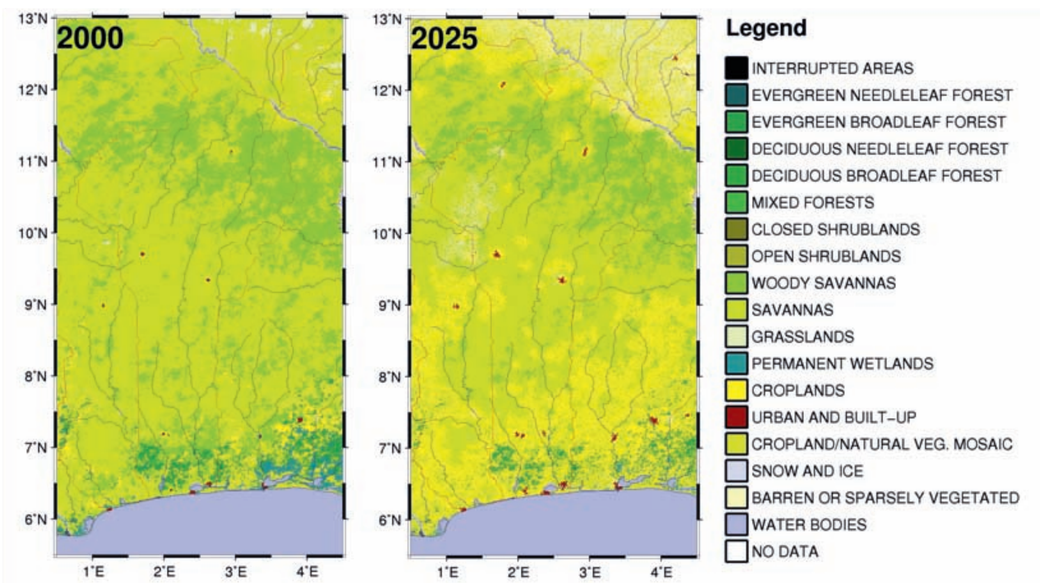

***Fig. 1:** Observed land cover in 2000 and simulated land–cover changes until 2050 in Benin and neighbouring countries, based on 1 x 1 km² land–cover pixels from USGS/GLCC (Hagemann 2002).*

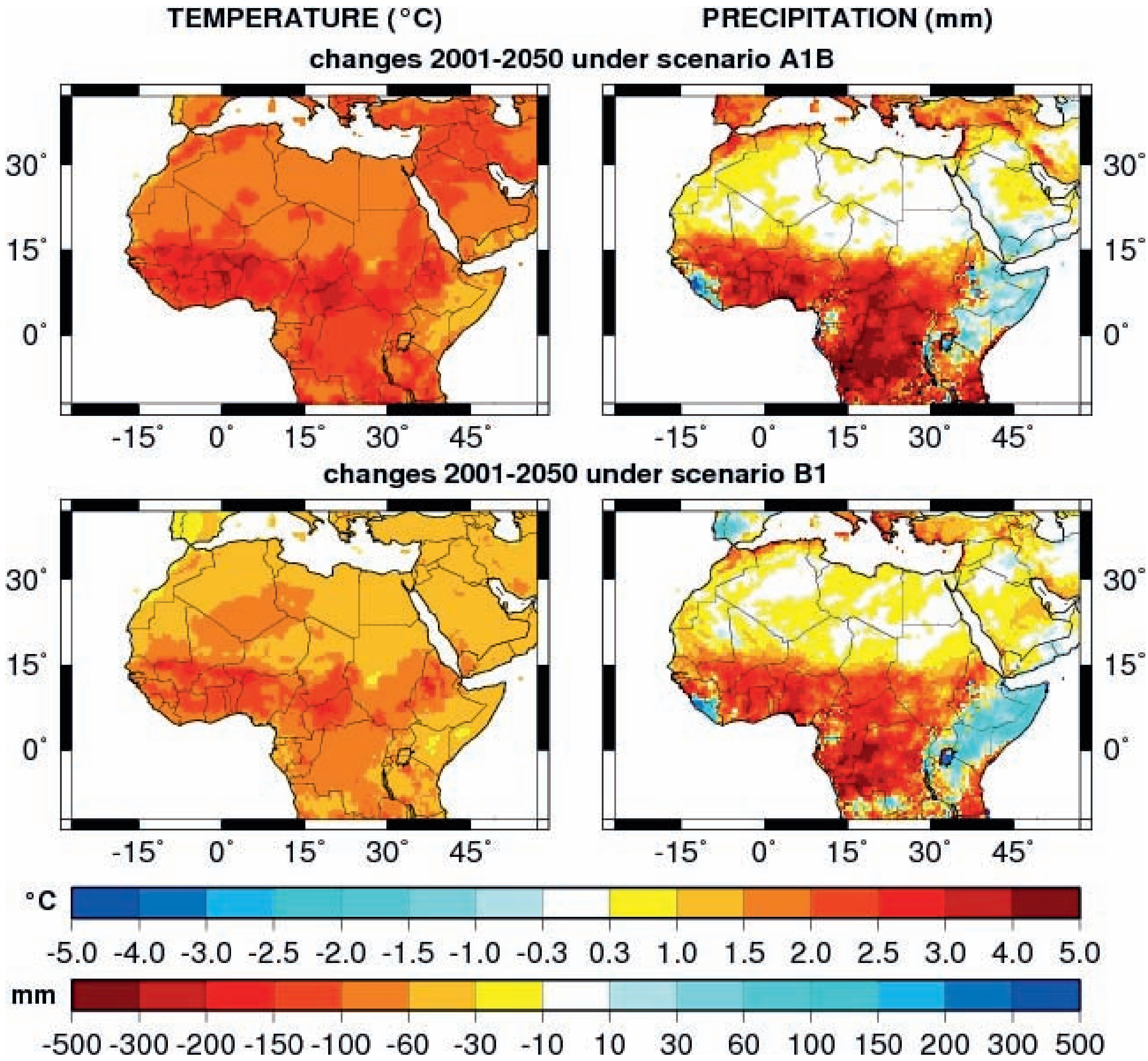

Fig. 2: *Projected changes in annual precipitation and near-surface temperatures until 2050 over tropical and northern Africa due to increasing greenhouse gas concentrations and man-made land cover changes.*

Both scenarios suggest to a prominent warming over all land masses, with the highest amplitude in sub-Saharan Africa where the strongest land cover changes are imposed. The B1 scenario is associated with a 1 °C lower warming rate until 2050. Both scenarios suggest a dramatic weakening of the hydrological cycle over most parts of tropical and subtropical Africa, which can be explained by reduced evapotranspiration and a cut off of the local water recycling in the tropical atmosphere.

The projected rainfall decrease until 2050 is 25 - 30 %, which is comparable to the observed decline after the 1960s. Scenarios A1B and B1 are nearly identical in predicting this drying tendency.

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6

Impact of Climate Change on Malaria Risk in West Africa

Volker Ermert, Andreas H. Fink, Andrew P. Morse, Anne E. Jones and Heiko Paeth

Malaria is one of the most serious health problems in the world. Projected climate change will probably alter the range and transmission of malaria. Potential changes to malaria transmission are assessed by forcing the Liverpool Malaria Model (LMM) with data from ensemble scenario runs of the state-of-the-art Regional Model (REMO). Due to a dryer rainy season the malaria projections show a decreased spread of malaria in most parts of West Africa, but the epidemic risk increases in more densely populated areas.

Introduction

Malaria is one of the most important infectious diseases in the world, causing about 273 million clinical cases and 1.12 million deaths annually. More than 40% of the global population (>2.1 billion people) are exposed to the malaria (Touré and Oduola, 2004). At least 90% of the more than 1 million annual deaths occur in sub-Saharan Africa (Greenwood et al., 2005).

Malaria Modelling

In order to assess the occurrence of malaria in West 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, which are discussed below. The proportion of the population that are carriers 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.

Data

LMM simulations 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 Model (REMO), which takes into account land use and land cover. 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.

Results

On the basis of the transect station data (1973–2006), the LMM shows 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. 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 LMM simulations show a decrease in the malaria prevalence from the Guinea Coast towards the Sahel for the period 1960 to 2000. The regions of epidemic malaria occurrence, defined by a large inter-annual variability of the annual malaria prevalence maximum, lie between 13 and 18°N (Fig. 1). Further south, the malaria spread in the simulated population is more

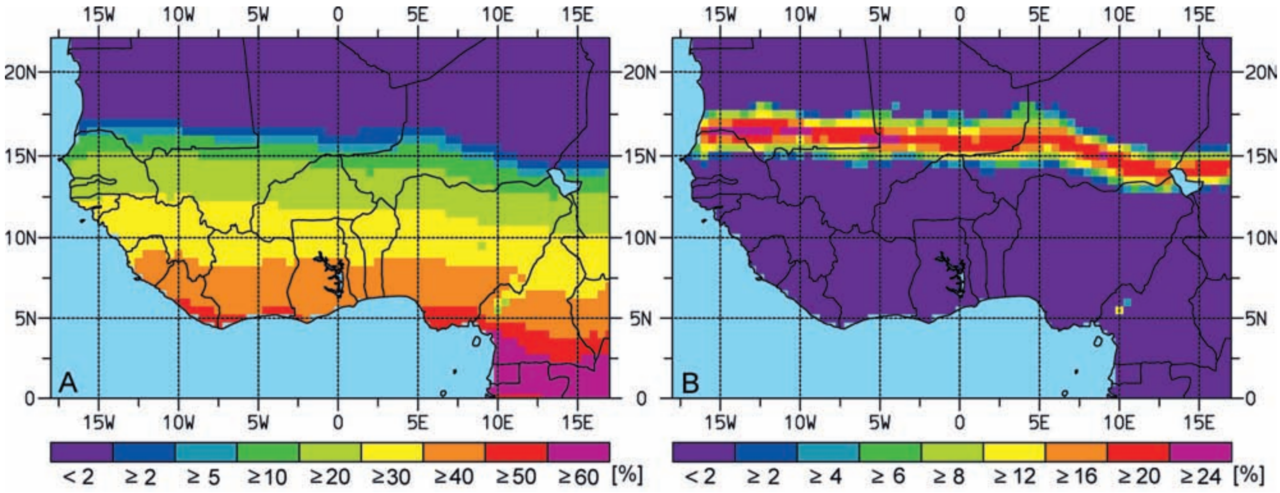

Fig. 1: *(A) Annual averaged model prevalence (in %) and (B) standard deviation regarding the annual maximum of the model prevalence (in %) for 1960 to 2000 based on LMM ensemble simulations.*

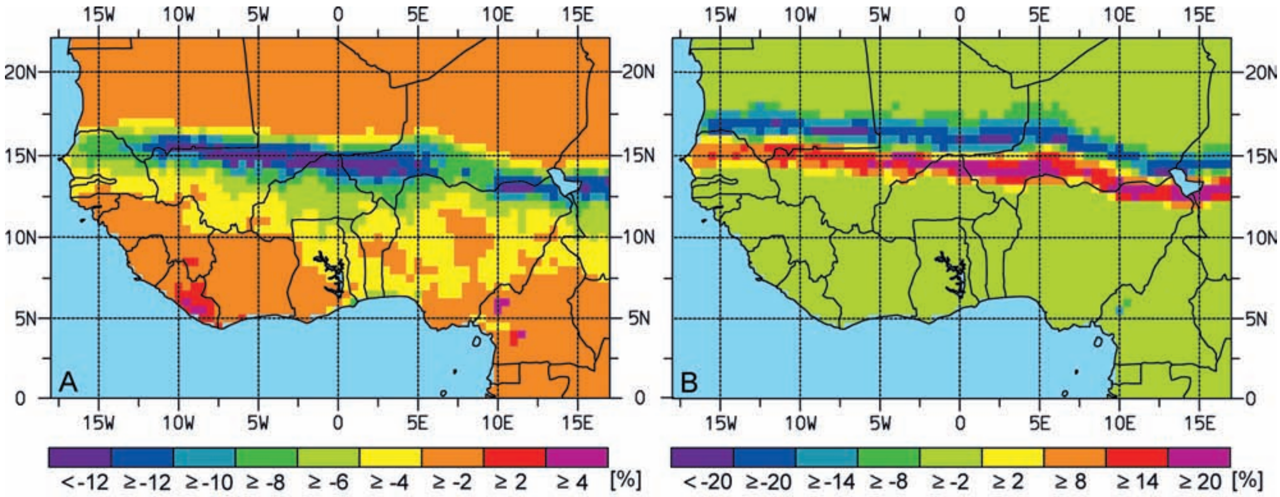

Fig. 2: *(A) Differences in the annual average model prevalence (in %) and (B) in the standard deviation regarding the annual maximum of the model prevalence (in %) between the last decade of the A1B scenario (2041–2050) and the period 1960 to 2000.*

stable from year to year and is thus classified as endemic.

Largely due to the land surface degradation, REMO simulates a prominent surface heating and a significant reduction in annual rainfall amount over most of tropical Africa in both scenarios (↗5). As a consequence, the malaria projections show a decreased spread of the malaria disease in most parts of West Africa for the decade 2041 to 2050 (Fig. 2). 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 is 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 remains stable (Fig. 2B). However, due to a drier and shorter rainy season the malaria transmission period will be shorter.

The results regarding the LMM ensemble runs for scenarios A1B and B1 are similar to each other. 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.

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7 The Climate of Benin (1961 to 1990)

Volker Ermert and Tim Brücher

Benin has a sub-humid tropical climate that is largely controlled by the West African monsoon circulation. The bulk of the annual precipitation is received during the rainy season of the boreal summer. The dry season is characterised by dry, dusty, northeasterly Harmattan winds.

Key climate factors: the ITF and ITCZ

Benin is situated in a transition zone between the equatorial tropical climate in the south and an arid steppe climate in the north. The sub-humid climate of Benin is affected by both the cool and humid monsoon air mass, as well as the hot and dry Saharan air mass. The Inter-Tropical Front (ITF) defines the border between these two air masses. Due to the shallow depth of the monsoon layer just south of the ITF, the ITF region is generally associated with fair weather. The ITF is located at approximately 7° N in January, and extends as far north as 20° N in August. As a result, Benin's coastal region is situated in the humid south-westerly monsoonal flow throughout the year. This is reflected in the minimal annual variation in the average relative humidity, remaining above 60 % throughout the year (see Cotonou in Fig. 1). However, several days during the winter months (December-March) are prone to dry spells, due to the dusty Harmattan winds.

The Inter-Tropical Convergence Zone (ITCZ) is defined by the maximum water vapour convergence in a tropospheric column. The ITCZ is located between 6° and 10° latitude south of the ITF, and can be delineated in rainfall charts by the zone of maximum precipitation.

Data

The climate data for Benin for the Climatological Normals (CLINO) period (1961–1990) were taken from the World Meteorological Organization (WMO; WMO 1996). Rainfall statistics were derived from monthly precipitation data from the Global Historical Climatology Network version 2 (GHCN; Peterson and Vose, 1997).

The dry and rainy seasons

Between November and March, Benin's central and northern regions are located north of the ITF. The northeasterly trade winds, known as the Harmattan, prevail. The Harmattan blows across the Sahara desert, and is therefore dry and dusty. Between November and January, the Harmattan airflow is cool, and affords a cool dry season. From February to April the Harmattan air mass is increasingly heated due to the approaching overhead position of the sun. During this hot, dry season, the highest annual temperatures are observed, with mean daily maximum temperatures of 38.6 °C in April at Kandi (Fig. 1). The strong daytime insolation and the clear, dry nights lead to a large mean daily temperature range exceeding 17 °C at Kandi in February (Fig. 1). On the contrary, the wet and cloudy period in the boreal summer (April to September) is characterised by a lower diurnal cycle of temperature, with ranges of only 8.4 °C at Kandi in August (Fig. 1).

During March and April, the increasing solar radiation over the Sahel and Sahara regions causes a strengthening, northward progression of the continental heat low. In its wake, the relatively cool, moist, and convectively unstable monsoon air penetrates farther into the continent. In April, the climatological position of the ITCZ is located over the Gulf of Guinea. However, the greater depth of the monsoon layer, and the short-term northward excursions of the ITCZ cause the first substantial rainfalls in the littoral (e.g. Cotonou, Fig. 1). The peak of the first, more intense rainy season is observed in June (↗9) . Farther to the north of Benin, the start of the rainy season is delayed until May or June. At the end of June, the ITCZ abruptly moves to approximately 10° N, resulting in abundant rainfall and cloudier conditions in central and northern Benin. North of Savè, the peak rainfall periods occur between July and September. During this time, the littoral is affected by the "little dry season", which is directly related to coastal upwelling, colder sea-surface temperatures, and the resulting drop of rainfall. The swift retreat of the ITCZ toward the equator from September to November causes a second, less intense rainy season in the South. By the end of November, the ITCZ is situated far from the coast, over the equatorial portions of the Gulf of Guinea. Figure 1 indicates the low rainfall amounts at the core of this dry season during the December to January period over all of Benin.

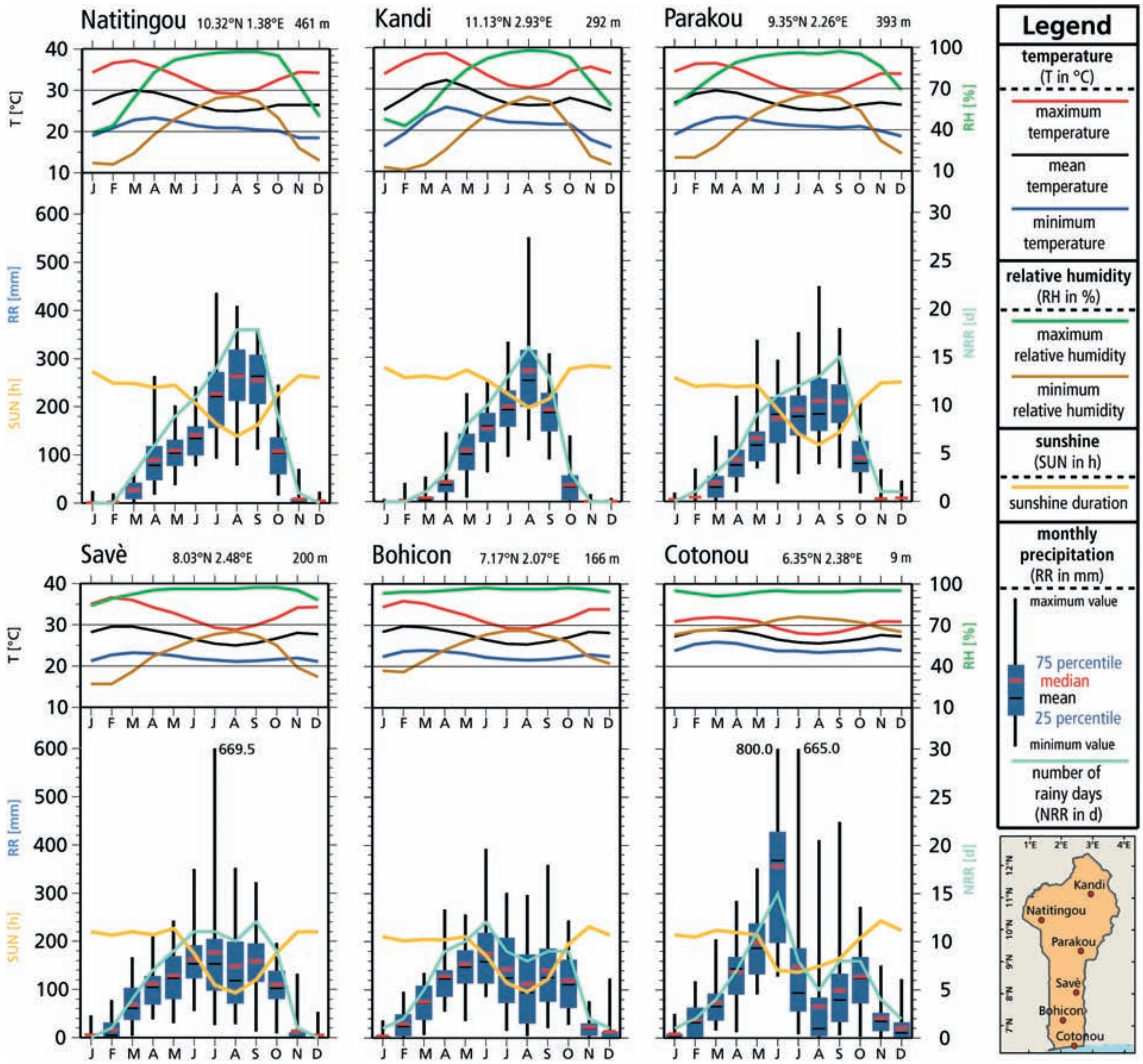

Fig. 1: Locations of the six synoptic stations of Benin and their climate charts (CLINO, 1961–1990) displaying long-term monthly means. Indicated are mean (T), mean daily maximum (T_{max}) and minimum (T_{min}) temperatures (in °C), mean maximum and minimum relative humidities (RH in %), monthly sunshine totals (SUN in h), and the number of days with more than 1 mm of rainfall (NRR in d). The monthly precipitation amounts (RR in mm) are provided for the mean, the median, the range (of the 25 to 75 percentile), and the absolute values.

***Tab.1**: Long-term annual mean values for the six synoptic stations (cp. Fig. 1).*

Station	T [°C]	T_{min} [°C]	T_{max} [°C]	RR [mm]	NRR [d]	SUN [h]
Kandi	27.7	21.0	34.3	1008	67	3045.2
Natitingou	27.0	20.8	33.2	1232	89	2678.4
Parakou	26.8	20.9	32.6	1150	87	2510.0
Savè	27.4	21.9	32.8	1105	75	2203.6
Bohicon	27.6	22.6	32.5	1105	77	2176.8
Cotonou	27.2	24.3	30.1	1309	75	2345.1

In general, there is a meridional rainfall decrease. However, averaged annual precipitation amounts in Natitingou are an exception due to orographic-induced rainfall over the Togo-Atakora low mountain range (Tab. 1).

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8 Observations of Past and Present Rainfall in Benin

Malte Diederich and Clemens Simmer

Archived rain measurements started in Benin during the 1920s, with few meteorological stations in the main cities, and have grown to a network of nearly 120 measurement sites in 2006. Although the spatial coverage of measurements was not dense in early years, and only few stations provided regular high resolution measurements, the archive accurately describes climate variability on a coarse scale.

Annual rainfall and interannual variability

In northern Benin, the total annual rainfall falls in a single rainy season, which typically lasts from April to October. The largest monthly rainfall values are in August, while in the south the bimodal annual rain distribution can be separated into a strong rainy season from mid-February to early August, and a weaker one from mid-August to November (Fig. 1 and 2, ↗7, ↗9).

All regions of Benin are subject to perceivable climate variability that reoccurs every 2 to 50 years. The interannual variability is highest in the south, with area-averaged sums ranging from 800 to 1800 mm per year (Fig. 3), and the number of rainy days ranging from 45 to 95 per year (Fig. 4).

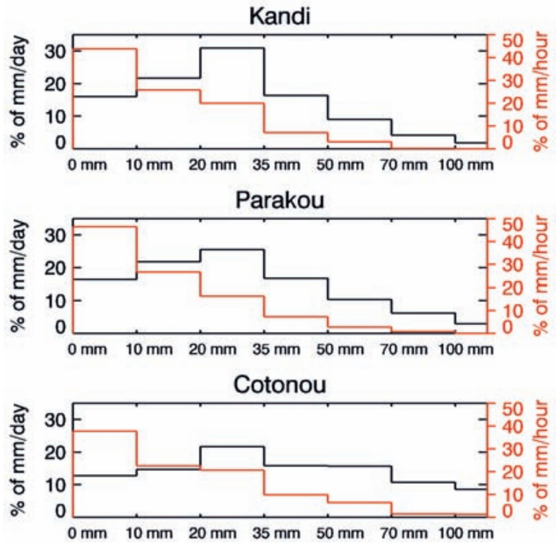

Fig. 2: Contribution of seven intensity-classes (0–10, 10–35, 35–50, 50–70, 70–100, and above 100 mm) of daily (black) and hourly (red) rainfall to the total rainfall amount according to gauge measurements at three locations.

Distribution of rainfall intensities

The probability-distributions of daily and hourly rain sums are shifted towards high intensities as one goes from north to south (Fig. 2). All three regions

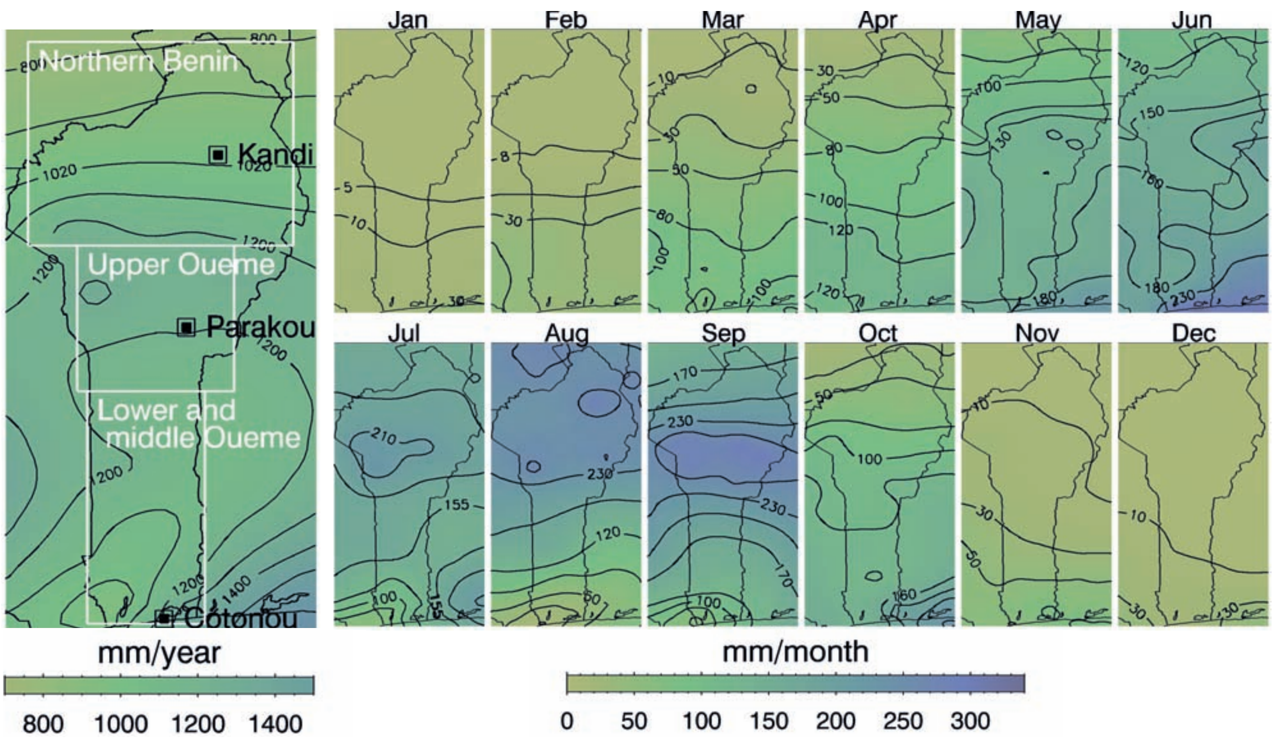

***Fig. 1**: Left: Mean annual rainfall 1921–2004. Right: Mean monthly rainfall 1921–2004.*

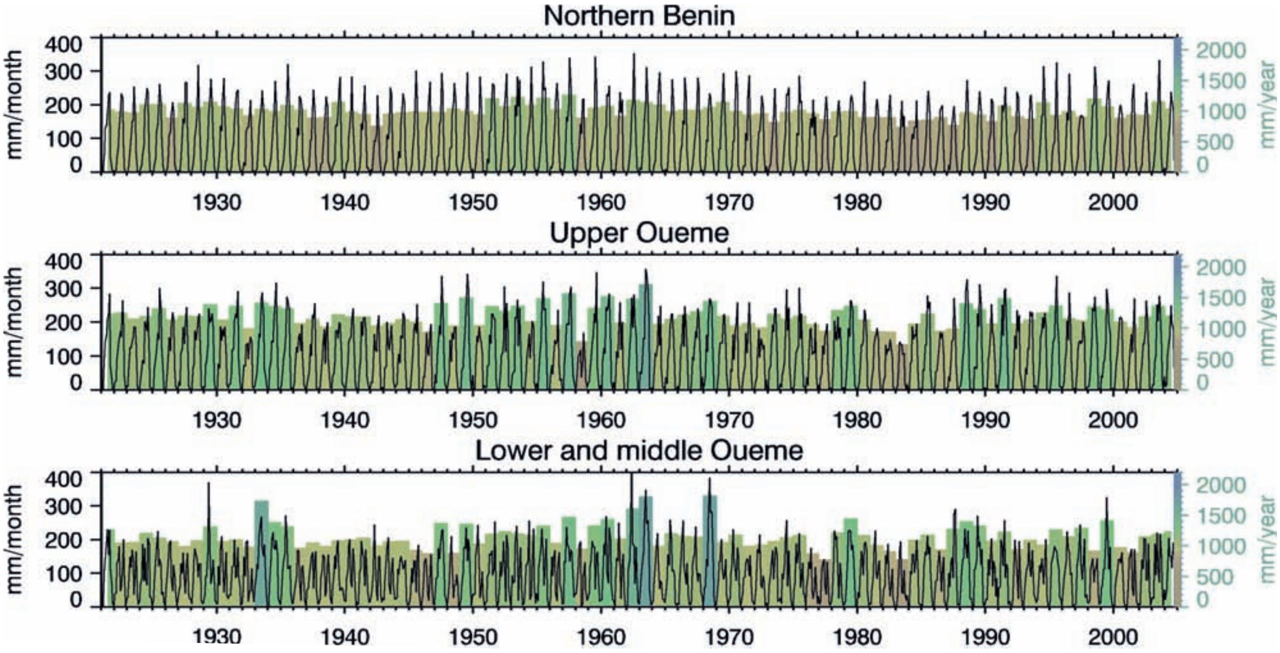

Fig. 3: Monthly (black lines) and yearly (colored bars) rainfall averaged over three regions of Benin.

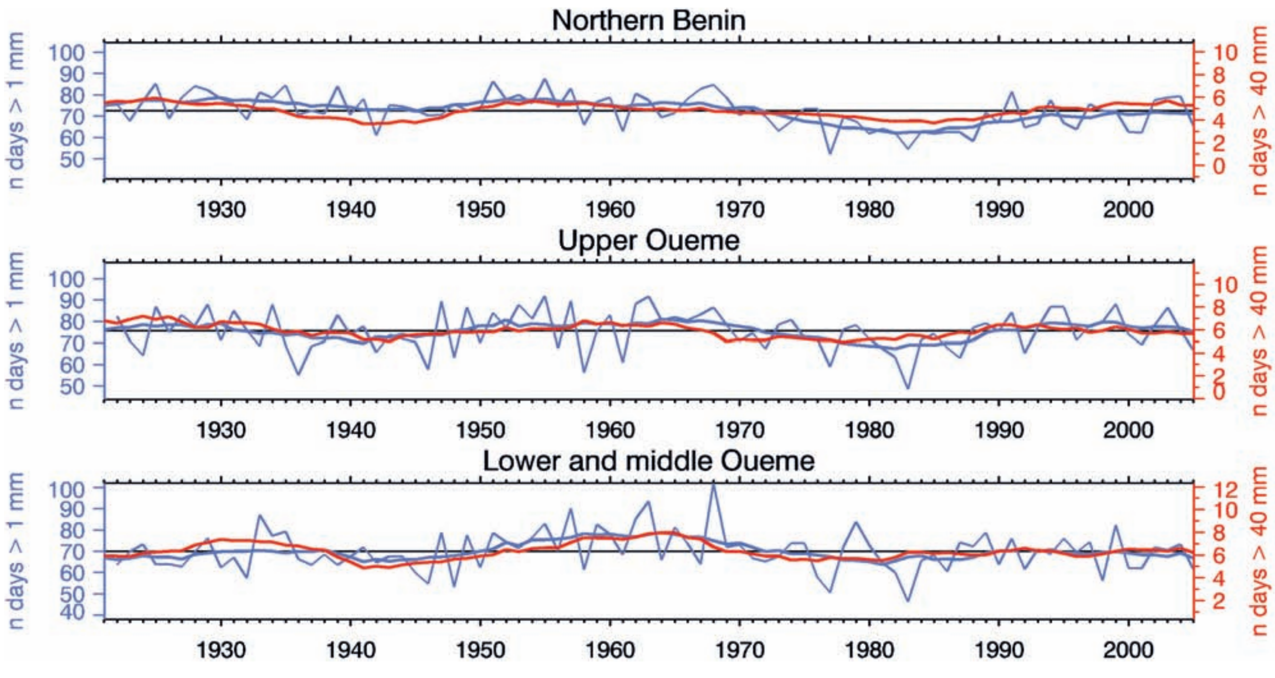

Fig. 4: Number of rainy days per year (thin blue line, bold blue line average number over 11 years) and number of days with over 40 mm of precipitation per year (#RR40: bold red line average over 11 years) measured by stations in three regions of Benin (Fig. 1). The black line marks the mean from 1921–2005.

exhibit the strongest positive rainfall anomalies in the early 1960s, and the strongest negative anomalies in the early 1980s (Fig. 3). Along with the decline in total rainfall, northern Benin has experienced a strong decline in rainy days per year during the 1980 dry period, while the number of extreme events (> 40 mm, 92 % quintile) exhibited a similar minimum during the dry period in the 1940s (Fig. 4).

Acknowledgments
IMPETUS thanks the National Meteorological Service of Benin and the Institut de Recherche pour le Développement (IRD) for contributing the measurements of daily rainfall (BDMET) and the hourly rain intensities (BDNUM).

9

Spatial and Temporal Rainfall Climatologies of Benin

Andreas H. Fink, Susan Pohle and Ralf Hoffmann

Based on the mean total annual rainfall, rainfall evolution during the rainy season, and the occurrence of rainfall during the course of the day, Benin can be divided into distinct rainfall regions.

Methodology

The 93 available rainfall stations in Benin experienced data gaps in their daily rainfall records in the climate normal period from 1961 to 1990. Of the 42 stations that entered the present study, each met the following criteria: (a) the number of missing values was under 10 % for a given year, and (b) more than 80 percent of the annual rainfall totals were available for the period from 1961 to 1990.

The likelihood of rainfall during the day at six synoptic weather stations in Benin was calculated as the percentage of rainfall occurrence during the 96 15-minute intervals between 00 and 24 UTC for the 29-year period from 1962 to 1990.

Mean annual rainfall

The map of the mean annual rainfall (Fig. 1, right panel) over Benin shows several striking features. Firstly, a west-east gradient is observed along the coastal strip, with the highest national rainfall amounts near the Nigerian frontier (Seme: 1485 mm) and a dry zone with less than 1000 mm near the Togolese frontier. The latter represents the northeastern tip of the coastal Ghana-Togo dry zone (Vollmert et al., 2003). Secondly, higher rainfall amounts in the Beninese parts of the Togo-Atakora low mountain range (Djougou: 1309 mm) are also evident. Finally, the map indicates the strong northward rainfall decrease north of 10° 30′ N, with the driest national station being Malanville (787 mm).

At least three seasonal rainfall regimes (Fig. 1, left panel) are found in Benin. These include: (a) a bi-modal rainfall distribution between the coast and 7° 30′ N, with the first rainy season being more intense (e. g. Cotonou and Sakete), (b) a broad peak with indications of either a weak tri- or bi-modal distribution at some stations in central Benin (e.g. Savè and Parakou), and (c) a clear uni-modal signal characterized by a slow increase in rainfall and a sudden decrease (e. g. Kandi) (Adam and Boko, 1993).

Diurnal rainfall

Like in other parts of West Africa, the diurnal peak of rainfall probability varies across Benin depending on the distance of a given station to the ocean and major tropographic features. For example, the inland propagation of the land-sea breeze circulation in the course of the day causes a morning maximum at Cotonou, and a pronounced afternoon maximum at Bohicon (Fig. 2). Another example is the primary or secondary probability peak after midnight at the northern stations at Parakou, Kandi and Natitingou (Fig. 2). At this time of day, large thunderstorm clusters, which were generated in the late afternoon over the central Nigerian highlands, then propagate westward at about a constant speed of 50 km h^{-1}, arrive over north-central Benin (Fink et al., 2006).

Acknowledgements

We are grateful to C. Depraetere and J.-M. Bouchez from the Institute de Recherche pour le Development (IRD), as well as to the National Weather Service (DMN) for providing us with the rainfall data.

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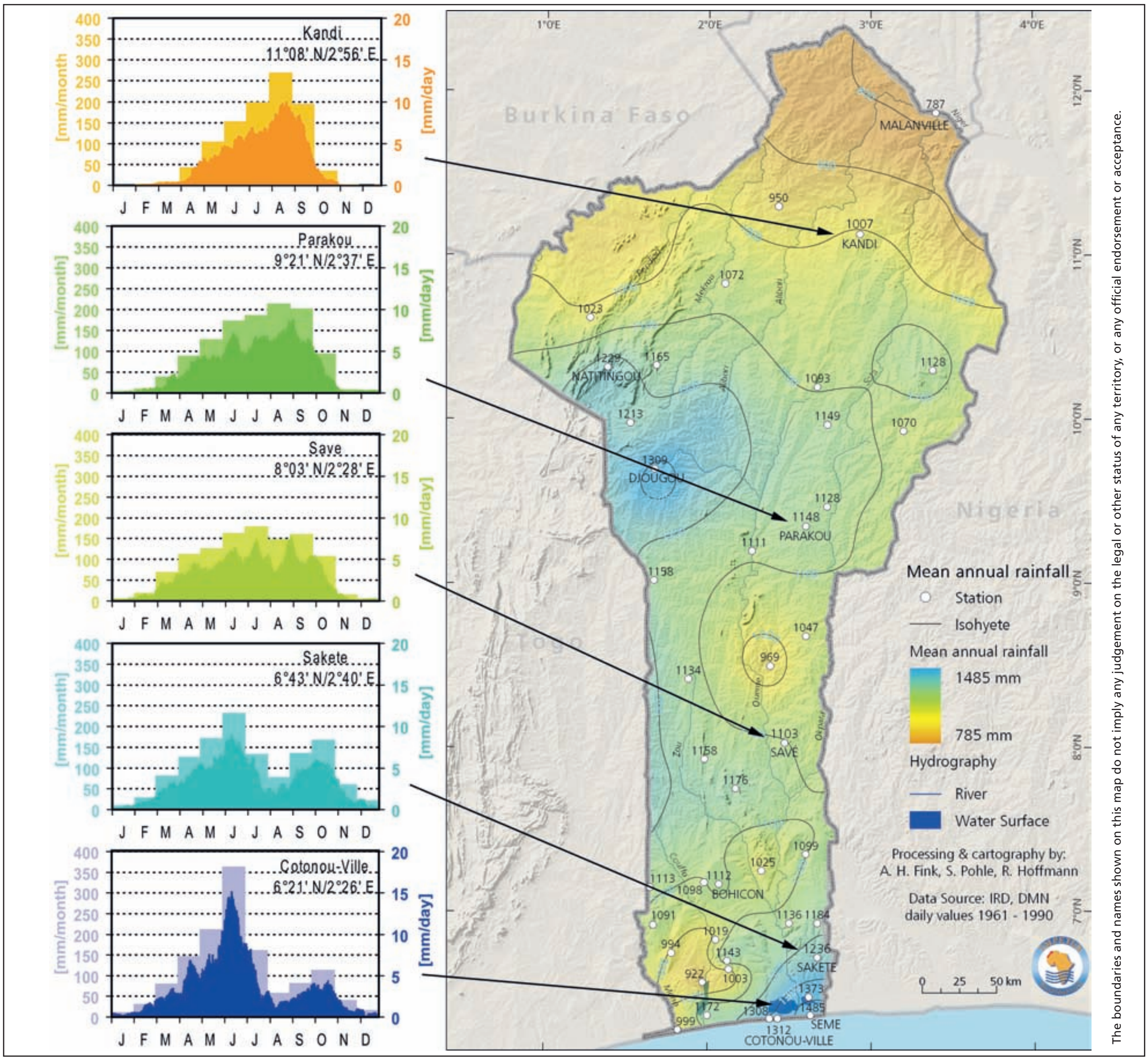

Fig. 1: *Mean (1961–1990) monthly rainfall amounts (left abscissa) and daily rainfall (right abscissa) expressed as the 11-day running mean of the 1961–1990 mean daily rainfall for selected stations (left). Map of mean annual rainfall (in mm) for the period from 1961 to 1990 (right).*

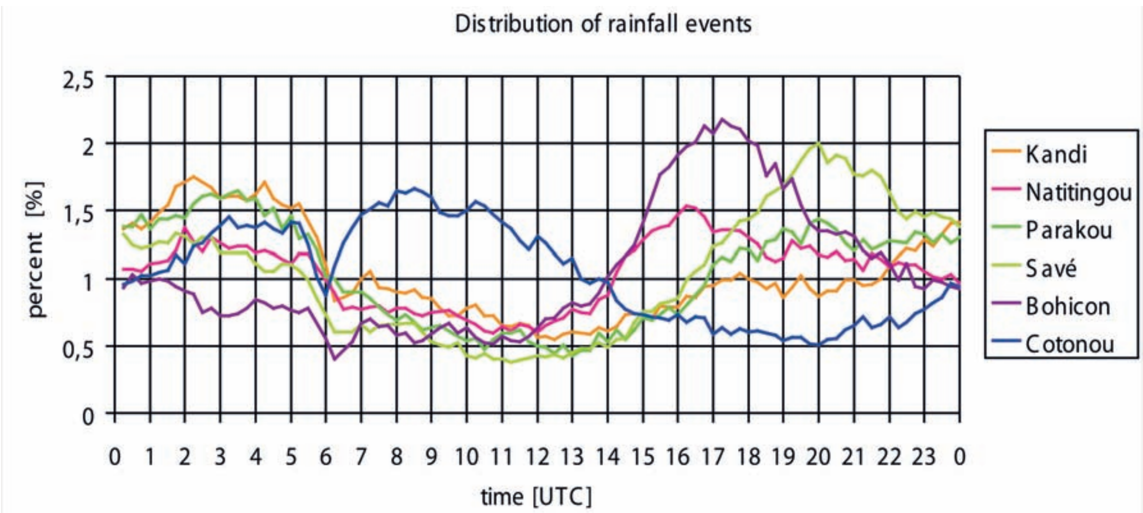

Fig. 2: *The diurnal cycle of rainfall probability expressed in percent for 15-minute intervals between 0 and 24 UTC for the period 1962 to 1990 (1961 missing).*

10 Changes in Benin's Monsoon Climate

Heiko Paeth, Kai Born and Kai Oliver Heuer

Benin is part of the Guinean Coast region, which is characterized by a prominent monsoon climate with marked dry and wet seasons. Within the summer monsoon period, dry spells occur regularly, and endanger agricultural production and food security. Herein, we discuss a regional climate model that is able to resolve atmospheric processes at the synoptic scale. This model allows us to address future changes in the seasonality and dry spells of Benin's monsoon climate.

Model simulations

In order to evaluate current and future climate variations with high spatial detail in Africa, the regional climate model REMO has been developed and implemented. This model covers the region of tropical and northern Africa (Paeth et al., 2005), and accurately reproduces the observed features of African climate. Changes in the African climate have been modelled by forcing ensemble simulations of REMO to include increasing greenhouse gas concentrations and man-made land cover changes during the period from 1960 to 2050 (↗5). Based on these experiments, which are subject to realistic forcing conditions, a weather generator has been adjusted to available weather station rainfall data in Benin in order to compute local climates for past and future time slices. As such, climate change can be assessed at the scale of these weather stations.

Changes in dry spells

An important limiting factor for agricultural production in sub-Saharan Africa is the occurrence of dry spells during the summer monsoon season. Such monsoon breaks are associated with a shift in the intertropical convergence zone, which is synoptic to intraseasonal time scales. Figure 1 shows the dry spells along the Guinean Coast region and southern Sahel Zone calculated by modelling extreme value statistics. The top panel depicts the longest monsoon break during the May to October monsoon season, averaged over the 1961 to 1970 time period. While the longest monsoon breaks range between 5 and 15 days south of 10° N, which is not problematic for most crops in Africa, food production is endangered by longer dry spells north of 10° N. Thus, 10° N marks a natural boundary for agriculture lacking adequate irrigation. The bottom panel reveals the projected changes in the duration of extreme monsoon breaks through 2050. In large parts of sub-Saharan Africa, particularly in Benin, dry spell durations are statistically significant.

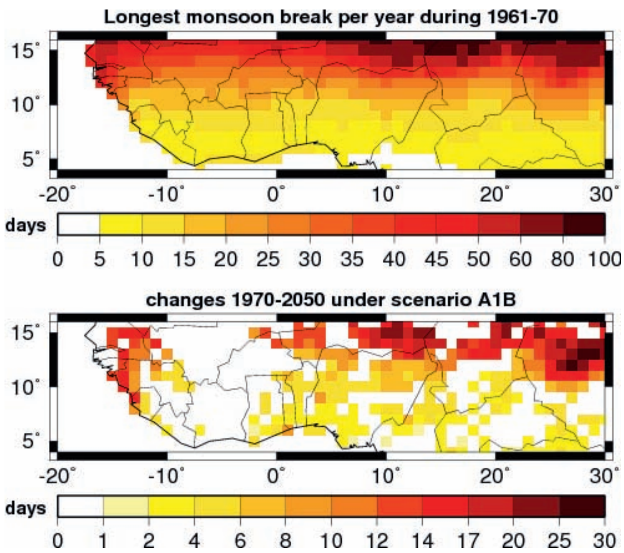

Fig. 1: *Longest monsoon breaks per year simulated during the summer monsoon period (May–October) 1961–1970, and projected changes until 2050. Only statistically significant changes, at the 5 % confidence level, are presented.*

Changes in mean climate

Figure 2 compares two classical climate diagrams at selected stations on a north-south transect in Benin, comparing past and future time periods. The station time series are derived from long-term simulations with REMO. The switch from bimodal (Cotonou) to unimodal (Kandi) rainfall distributions is well captured, and up through 2050, the model projects a dryer and warmer climate in Benin.

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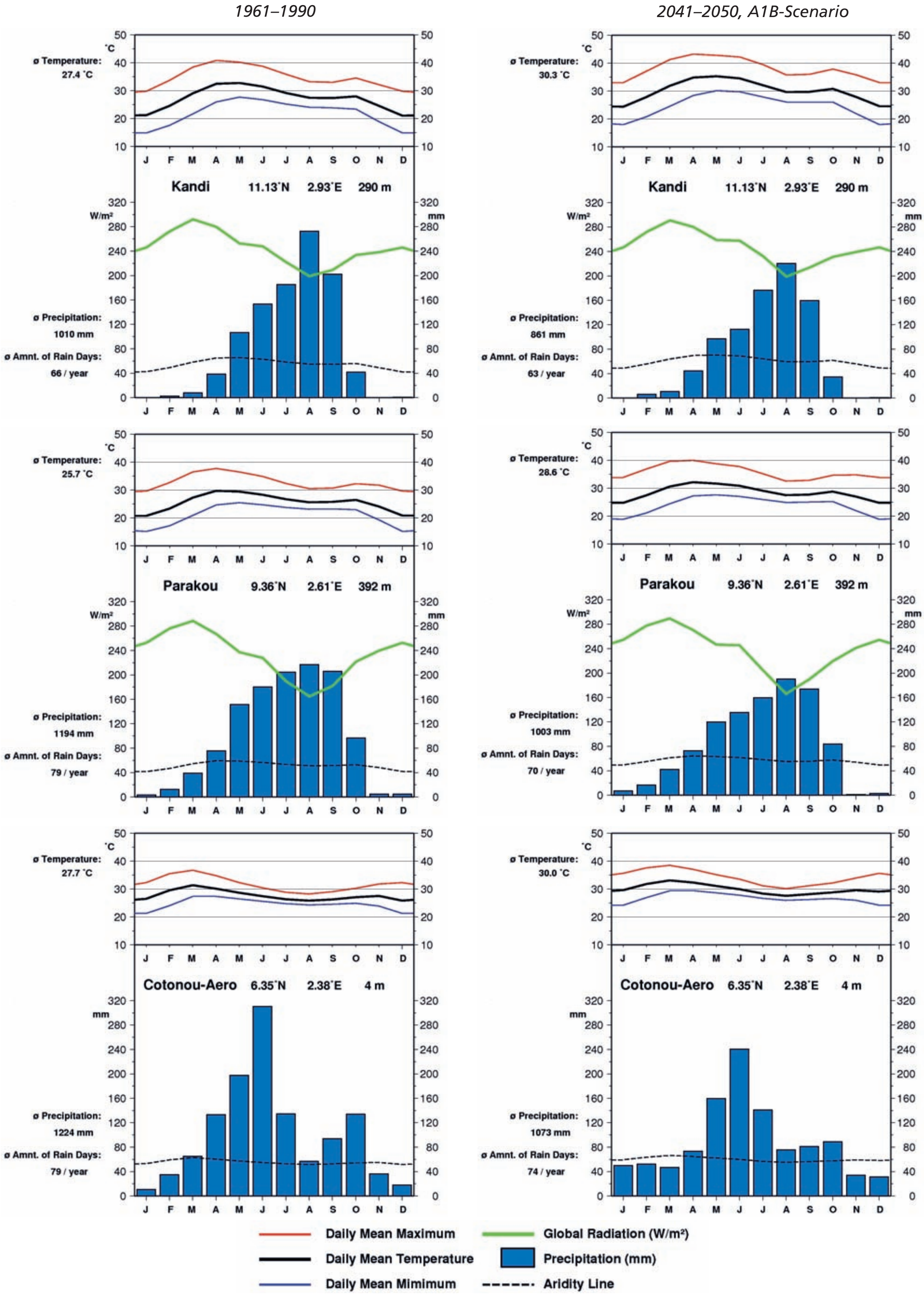

Fig. 2: Comparative climate diagrams at selected stations in Benin (1960–1999 versus 2041–2050 time periods), as simulated by the regional climate model REMO. Due to model output error, no global radiation is shown for the Cotonou station. Aridity line: after Walter, Lieth and Rehder, (1960).

11 Scenarios of the Regional to Local Rainfall Variability

Andreas Krüger and Kai Born

The high resolution models of the IMPETUS project (Lokal-Modell and FOOT3DK) estimate climate variability on a regional to local scale. For the studied regions, the identified key factors influencing local climate variability include variation of sea surface temperatures, which is included in larger scale climate predictions, and changes in land use, which have to be assessed from small-scale climate modelling. Both mechanisms are considered within the IMPETUS approach. Rainfall charts are presented for a control year, as well as for a future projection focusing on the rainy season of 2025 only.

Method

The explicit consideration of the influence of changes in land use on local rainfall patterns, which is a major factor for local precipitation development (Sogalla et al., 2006), is enabled through the interaction between several IMPETUS working groups. For both high resolution models of IMPETUS (Lokal-Modell (LM) and FOOT3DK), several complex and specific methods were applied to develop necessary and adequate surface boundary conditions. The role of sea surface temperatures, which is an important additional influence on local climate variability, is simulated implicitly by forcing smaller scale models with the coarser resolution models of the IMPETUS project (REMO and ECHAM5).

The LM simulations for the year 2025 were carried out based on REMO data. The focus of the studies was on this particular year of interest, and further pending investigations will permit the derivation of more general conclusions. The time slice realization was performed according to the B2 scenario of the IPCC SRES forcing.

Regional variability

For the LM simulations, land cover change (LCC) scenarios are calculated by a complex stochastic LCC model (↗5). Regional climate simulations with LM have been carried out for the entire Guinean coast region with 0.1° resolution for the years 2000 and 2025.

The comparison of the modelled rainy seasons for 2000 and 2025 (cf. Fig. 1a, 1b, and 1c) reveals high spatial variability of precipitation development throughout the complete simulation domain, although the rainfall pattern is highly preserved. In particular, in the north and northeast of the indicated LM area, annual precipitation is increased, while for regions in the south, southeast, and some parts at the northern border, dryer conditions are simulated. In contrast to REMO, which simulates a general trend towards dryer conditions (Paeth et al., 2007), the higher time and space resolution (time step one hour and mesh size 10 km x 10 km) of the LM, reveals a more heterogeneous pattern, despite being calculated for only a single year.

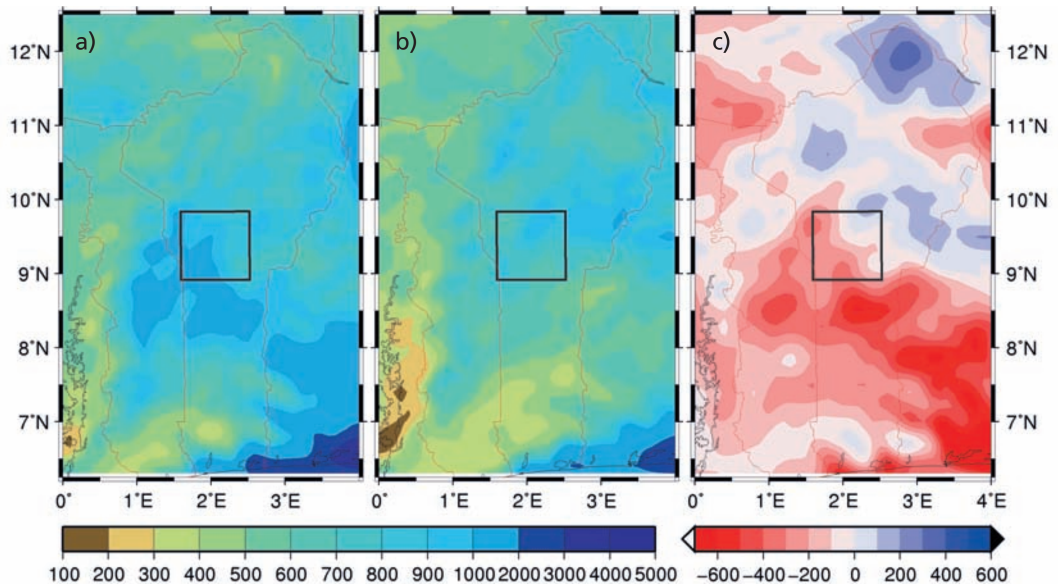

***Fig. 1**: Accumulated precipitation for the rainy seasons of 2000 (a) and of 2025 (b) and the difference of 2025 minus 2000 (c) calculated by means of the LM.*

Local variability

On the mesoscale (time step one hour and mesh size 3 km x 3 km), the precipitation for any desired rainy season is derived from a recombination approach using the model simulations with FOOT3DK.

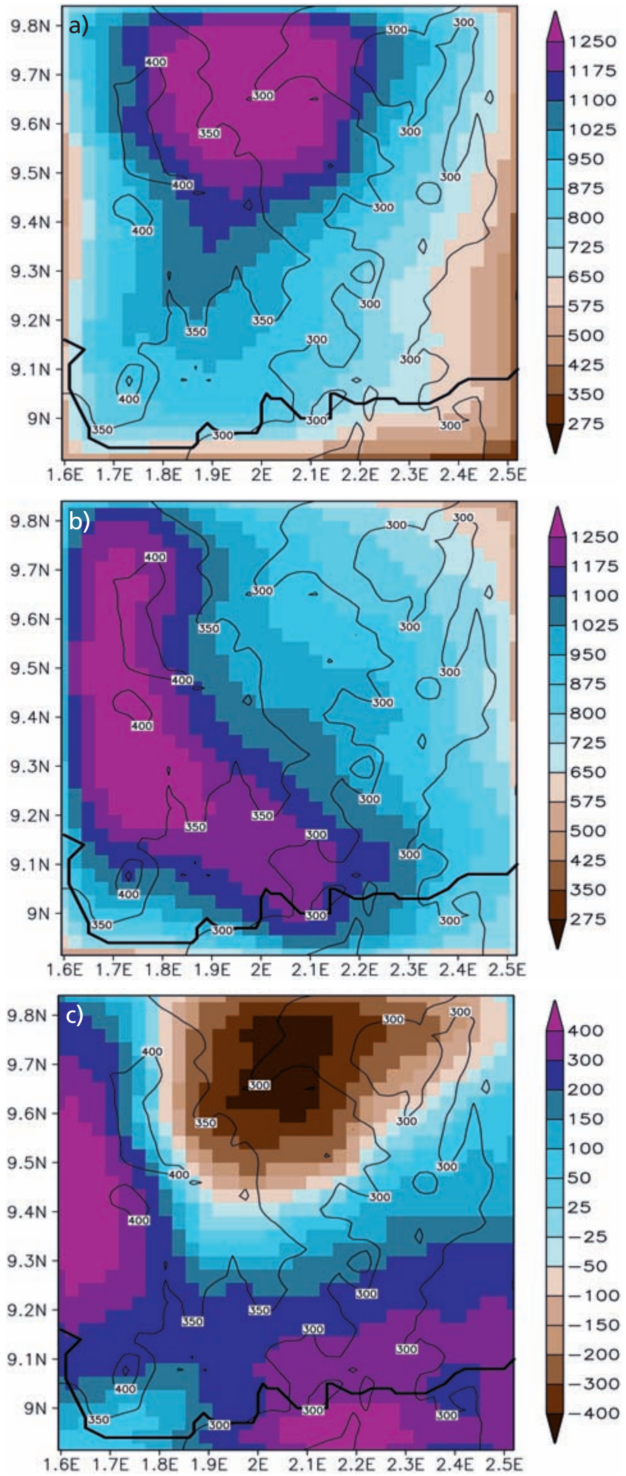

Fig. 2: Rainfall distribution for the years (a) 2002, (b) 2025, and (c) differences between the two. Isolines indicate orographie, and thick black lines represent the HVO margin. The first three rows at the margin of the simulation domain should be ignored, because boundary effects lead to unrealistic values.

To gather suitable episodes for the chosen recombination, a combined evaluation of satellite images and ground-based statistical analysis of rainfall characteristics was applied. Eight different types of cloud systems (cf. Fink et al., 2006) have been identified to build up the statistical basis for the recombination approach.

For the rainy season of 2002, thirty 54-hour episodes, which included all of the aforementioned cloud system types, were simulated and recombined. The resulting accumulated rainfall (Fig. 2a) agrees well with previous observations, although the observed maximum in the Haute Vallée de l'Ouémé (HVO) is located farther south (not shown), and values in the southeast of the domain are underestimated by 35 %.

On basis of LM model data, forty 72-hour episodes for the rainy season in 2025 were subsequently simulated. Additionally, a changed land register was used, which was specifically designed for the needs of FOOT3DK. It is based on land use change scenarios, developed within IMPETUS (Thamm et al., 2005). The HVO scenario rainfall was subjectively assigned to associated cloud systems by means of a comparison of similarities between rainfall characteristics of observed and simulated hourly precipitation amounts of FOOT3DK. In this manner, the distribution for the year 2025 (cf. Fig. 2b) displays a shift to the west compared to the major rainfall area of the year 2002 (cf. Fig. 2c). Unfortunately, the model results for the rainy season of 2025 are not statistically conclusive. Nevertheless, these preliminary results support the earlier findings of a growing risk of the occurrence of local rainfall extremes (dry and wet) due to future successive land surface degradation.

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Village people pumping water out of a well.

Water Availability, Water Consumption and Health

12

Gauged Sub-Catchments of the Ouémé River

Simone Giertz

River discharge data are essential to evaluate the available water resources of a catchment. In the Ouémé catchment, the national water authority of Benin *(Diréction nationale de l'eau (DGE))* runs a discharge observatory network in cooperation with the IRD *(Institut de Recherche pour le Développement)*. The gauges are mainly installed in the Ouémé River itself or in major tributaries like the Zou, Okpara and Térou. In addition, the IMPETUS project has installed river gauges in the small sub-catchment Aguima (↗17).

River gauges and discharge measurements
Twenty river gauges are available from the national observatory network in the Ouémé catchment (including IRD river gauges). The locations of the discharge gauges are shown in Fig. 1 and Tab. 1 provides information on the discharge gauges. In additional, five gauges have been installed by IMPETUS in the Aguima catchment.

Most of the gauges are equipped with automatic water level recorders to obtain water level continuously. At some gauges, the water level is read two times per day manually. During the rainy season, discharge measurements are carried out regularly at each gauge by the staff of the DGEau and IRD to determine the stage-discharge relationship. Based on this relationship and the continuous water level measurements, discharge is calculated continuously.

Delineation of sub-catchments
Sub-catchments were delineated with the Hydro-Tool extension of ArcGIS 9.1 based on the digital elevation model (DEM) of the SRTM mission. The Hydro-Tool uses the D8-method to derive the flow direction from the DEM. The resolution of the SRTM-DEM is 90 m x 90 m.

The areas of the delineated sub-catchments reach from 261 km² (We-We) to about 50,000 km² (Ouémé Bounou).

Tab. 1*: River gauges of the national observatory network in the Ouémé catchment.*

No. Map	Code DGE	Station	River	Data availability	Data gaps	Owner	Long.	Lat.	Size of Catchment [km²]
1	4501660	AGUIMO	AGUIMO	1997–2000		IRD	2.02	9.13	396
2	4501302	VOSSA	BEFFA	1953–1996	1960–1983, 1988–1990	DGEau	2.35	8.50	1932
3	4500106	AFON (DONGA)	DONGA	1996–2006		IRD	2.10	9.73	1308
4	4501690	DONGA-PONT	DONGA	1998–2006		IRD	1.95	9.71	587
5	4501103	KABOUA	OKPARA	1951–1997		DGEau	2.72	8.25	9464
6	4500104	AFON	OUEME	1983–2004	1993, 1994, 1999	DGEau	2.10	9.75	1188
7	4500105	PONT DE BETEROU	OUEME	1952–2004		DGEau	2.27	9.20	10083
8	4500107	BONOU	OUEME	1948–2002		DGEau	2.45	6.90	49285
9	4500118	PONT DE ZANGNANADO	OUEME	1986–1996		DGEau	2.47	7.22	38167
10	4500119	PONT DE SAVE	OUEME	1951–2002		DGEau	2.42	8.00	23491
11	4500121	TEBOU	OUEME	1997–2000		IRD	1.87	9.96	656
12	4501700	AVAL-SANI	OUEME	1999–2000		IRD	2.15	9.73	3279
13	4500130	SANI	SANI	1997–2000		IRD	2.12	9.76	745
14	4501603	WANOU (DOTE 238)	TEROU	1983–2002		DGEau	2.08	9.08	3060
15	4501650	SAR AMANGA	TEROU	1998–2005		IRD	1.82	9.23	1360
16	4501710	IGBOMAKO RO	TEROU	1998–2006		IRD	1.90	9.07	2323
17	4501505	WE-WE	WE-WE	1961–1999		DGEau	2.10	9.38	261
18	4501803	BAREROU	YEROU MARO	1983–1998		DGEau	2.37	9.35	2134
19	4501002	ATCHERIGBE	ZOU	1951–1999		DGEau	2.03	7.53	7035
20	4501005	DOME	ZOU	1952–1997	1959, 1960	DGEau	2.33	7.12	4083

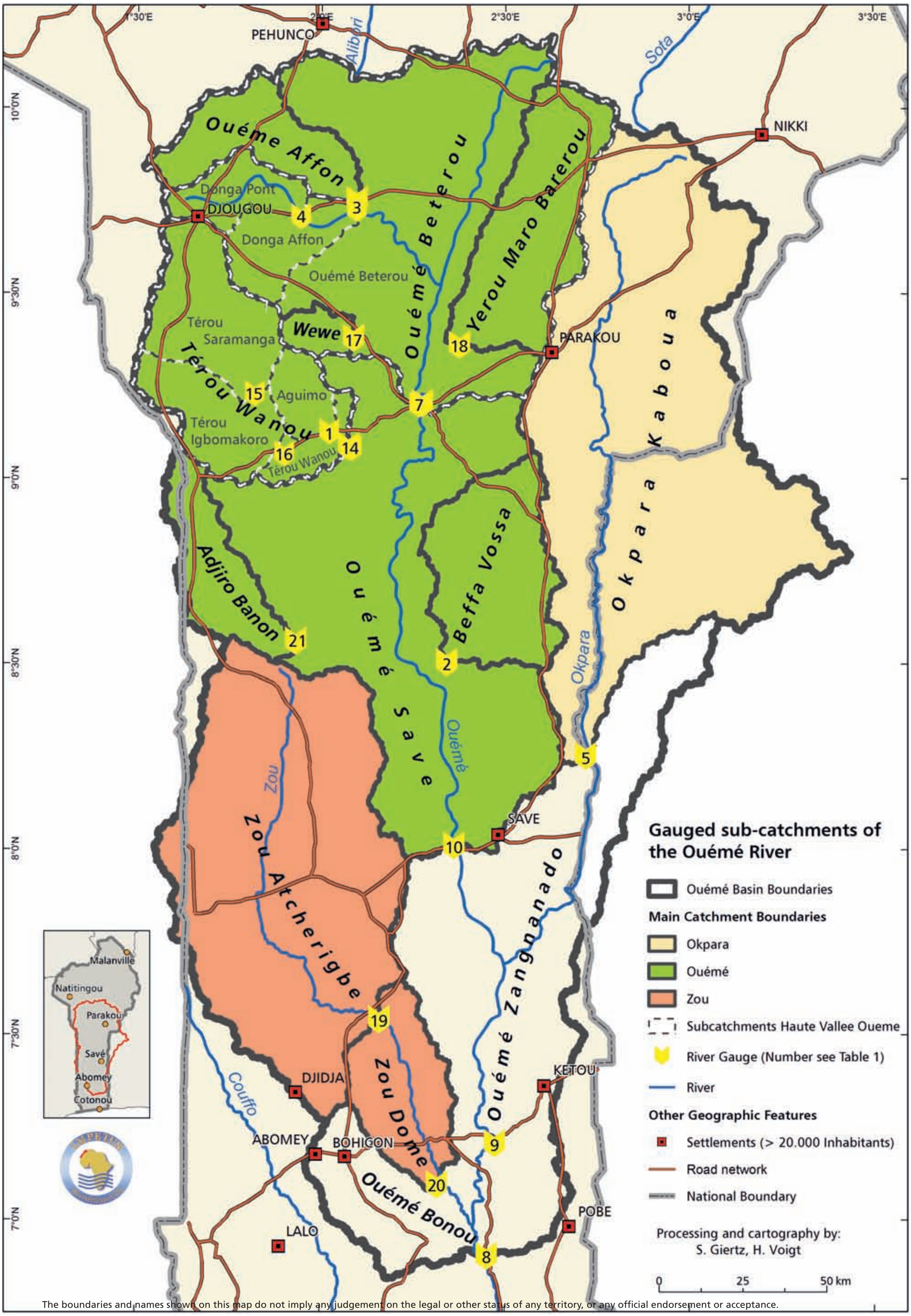

Fig. 1: Gauged sub-catchments of the Ouémé River.

13 The Hydro-Meteorological Network of the HVO

Andreas Fink and Simone Giertz

Data from the dense hydro-meteorological network in the "Haute Vallée de l'Ouémé" (HVO) catchment allow the investigation of various aspects of the terrestrial branch of the hydrological cycle in the Soudanian climate zone of West Africa.

Meteorological Instrumentation

Between 1997 and 2006, 65 pluviographs were installed by IMPETUS and CATCH / AMMA ("Couplage de l'Atmosphère Tropicale et du Cycle Hydrologique" / "African Monsoon Multidisciplinary Analyses"). IMPETUS and CATCH / AMMA provided 13 and 52 instruments, respectively. The rain gauges measure rain and its intensity at a resolution of up to 0.1 mm min^{-1}. Two types of instruments are in place; one is a tipping bucket and the other is a weighing gauge. These pluviographs are distributed unevenly across the 20,000 km^2 of the HVO (Fig. 1). One cluster of rain gauges is situated in the Donga catchment in the north-western HVO region. The IMPETUS cluster is located in the southern part of the HVO near the Aguima super site. At the time of writing, funding has been secured to run the network until the end of 2009. Furthermore, 11 pluviometers run by the "Direction Météorologique Nationale" (DMN) are manually read each morning.

Two automatic weather stations at Doguè and another at Djougou facilitate the analysis of surface meteorological variables as rainfall events pass by. In addition, the flux station at the Aguima super site measures wind, temperature profiles, humidity profiles, sensible heat flux, soil heat fluxes, and soil moisture.

The dense network enables the study of squall lines, the main rain-bearing systems in the Soudanian zone. In combination with satellite imagery, it is possible to categorise rain events, to analyse convection, and to calibrate rain estimations from satellite brightness temperatures or microwave images. Examples are described in Fink et al. (2006) and Schrage and Fink (2007).

Hydrological Instrumentation

The hydrological network consists of water level gauges, multi-parameter probes (conductivity, turbidity, and temperature), groundwater level measurements, and soil water measurements. In addition to the water level measurements of the "Direction Générale de l'Eau" (DGEau) at Ouémé-Beterou and Térou-Wanou, 18 water level gauges have been installed since 1997 by the CATCH-project (IRD) in the HVO in the Ouémé, Térou, and Donga Rivers and their tributaries. At all gauging stations, discharge measurements are performed regularly by the CATCH project to calculate the stage-discharge relationship. Discharge data are available since 1950 for the DGH stations and since 1997 for the CATCH gauges.

In order to analyse runoff generation processes and sediment yield, three multi-parameter probes were installed by the IMPETUS-Project in 2003. In the same year, 12 divers to monitor groundwater level fluctuations were installed in the HVO, 10 (plus a new one installed in autumn 2007) of which are currently recording water levels. Furthermore, 16 water level recorders run by the CATCH project are located in the catchment.

Finally, a dense measuring network, including five water level gauges, TDR-probes, and tensiometers, was established in small catchments (e.g., the Aguima catchment) in order to analyse the hydrological processes on a local scale.

The IMPETUS and CATCH/AMMA data are available through the AMMA data base at http://amma-international.org/database. Note that measurements at individual stations commence at different times, that the time series contain various data gaps, and that a registration of users at the AMMA data base is required to obtain the data.

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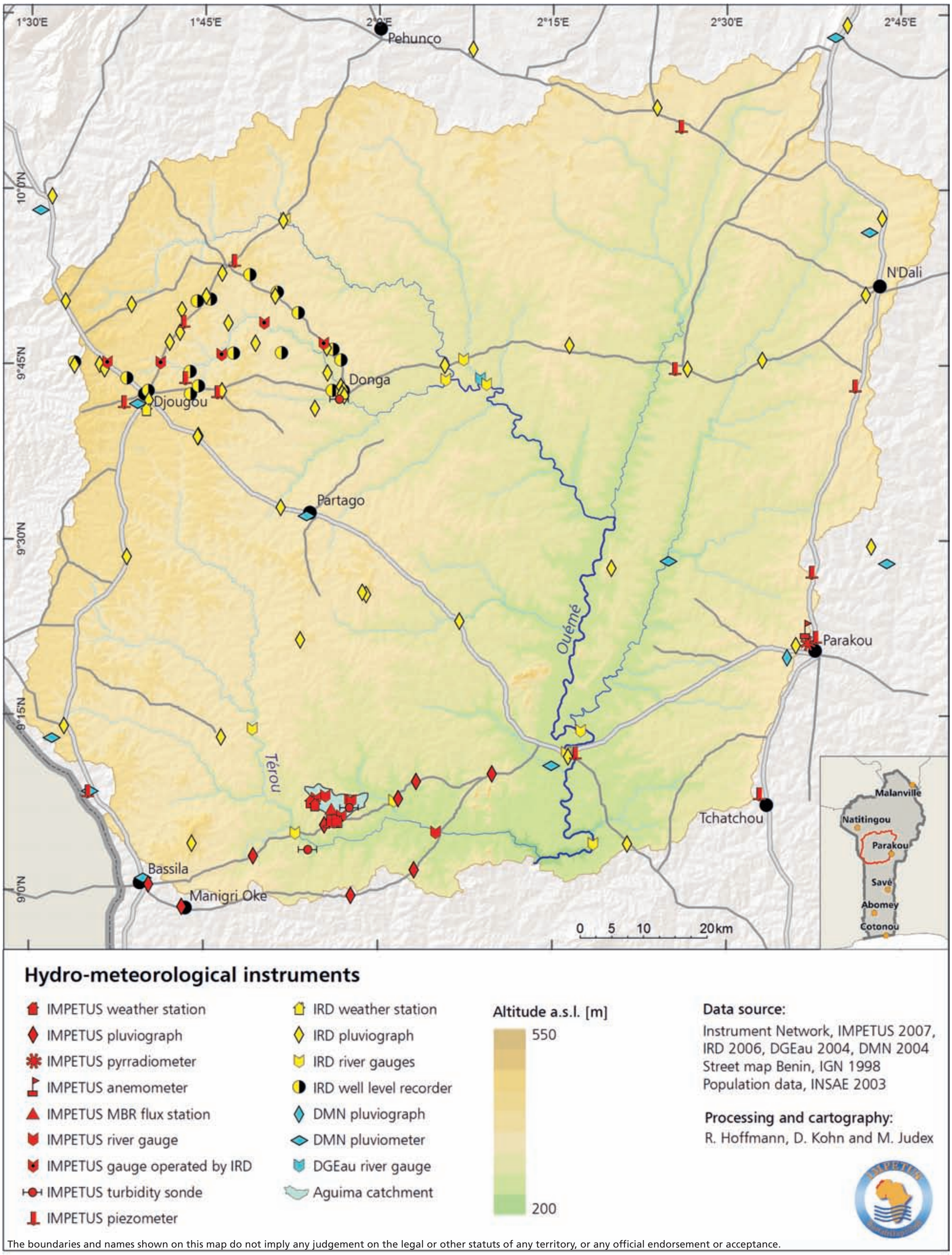

Fig. 1: *Network of hydro-meteorological instruments in the Upper Ouémé catchment, Benin. Further information regarding the instrumentation network can be found in the Internet:* http://www.impetus.uni-koeln.de *(IMPETUS) and* http://medias.obs-mip.fr/amma *(AMMA-France).*

14 Observation Points for Hydrochemistry and Piezometry in the Ouémé Catchment

Antoine Kocher and Tobias El-Fahem

To achieve a hydrogeological characterization of the Ouémé catchment, a number of observation points were selected. Water samples were taken from wells and boreholes according to geology and location, aiming at a better understanding of the groundwater dynamics. Additionally, the dynamic of the water levels was recorded by data loggers through several seasons, showing the vertical fluctuations of the water table.

Field sampling and measurements

During several field campaigns in the upper Ouémé basin (from 2004 to 2005) and in the whole catchment (since 2007), water samples from groundwater and surface waters were taken. Priority was given to groundwater samples from different depths for a depth-dependent, seasonally variable characterization of the groundwater chemistry. During the year, the groundwater table fluctuates by several meters (Fig. 1) and thus moves between the fractured aquifer system at the bottom and the saprolite aquifer at the top. Different chemical characteristics of both aquifers can be traced by the analysis of the water samples.

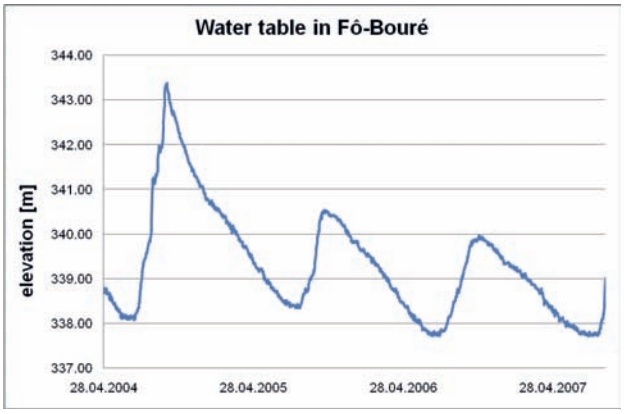

***Fig. 1:** Datalogger record in Fô-Bouré, showing water table fluctuations from 2004 to 2007, through the rainy and dry seasons.*

The parameters analysed are the major cations and anions, as well as Br^+, F^+, NO_3^{2-}, NO_2^-, NH^+, PO_4^3, SiO_2, Sr^{2+}, Fe^{2+}, and Mn^{2+}. Additionally, trace elements (As, Ni, Cu, Cd, Pb) were examined.

For each sample taken in the upper Ouémé catchment, the content of stable isotopes (Deuterium and 18-oxygen) was determined. Furthermore, stable isotopes were determined in rain water from three locations (Parakou, Djougou, and Sérou). The objective is to understand the mode of groundwater recharge in the study area, to determine the origin of the groundwater, and to characterize the general physico-chemical quality of the available water resources.

The field work also included measurements of the depth of the groundwater table. This is done by manual measurements with a light indicator during each field campaign. Continuous piezometric measurements are made by 12 automatic dataloggers (called divers) installed in the boreholes of pedal-pumps and of observation wells in use by the *Direction de l'Hydraulique*. Each diver takes measurements in a 3 hour interval. This allows obtaining data in the early morning hours when the water table in the pumped borehole has recovered sufficiently from the water extraction during the day time.

In summary, the water table fluctuations indicate a very dynamic system in which the global stock of water is affected by important seasonal changes. Hydrochemistry and isotopes confirm the local characteristics of the groundwater system. Thus, the limited system extension does not show high buffer capabilities, which could protect against the influence of external factors, such as change in rainfall regime or land use changes over a long time.

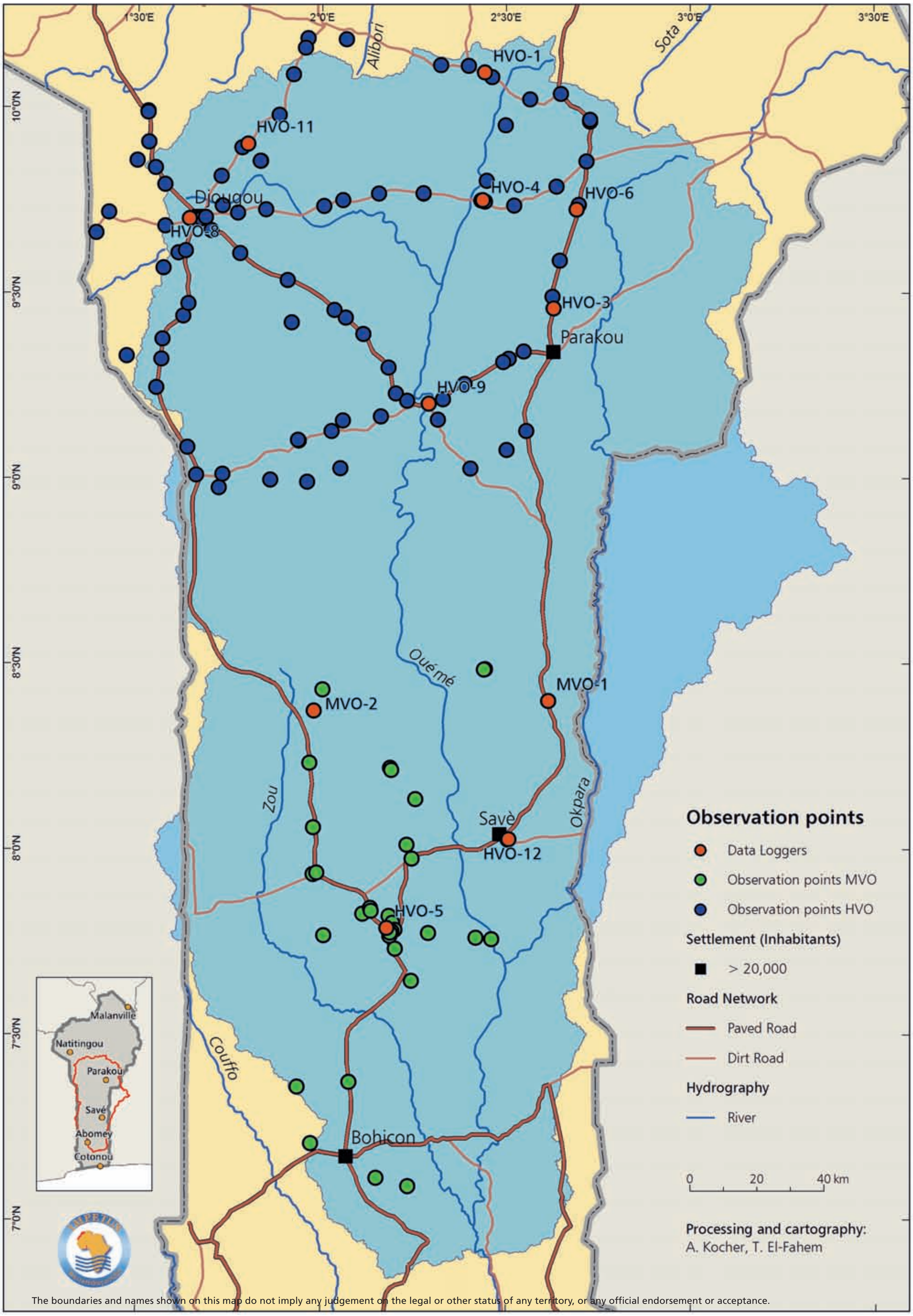

Fig. 2: Location of geo-hydrological observation points in the Ouémé catchment.

15

Hydrologic Modelling in the Ouémé Catchment at Local and Regional Scales

Simone Giertz and Gero Steup

Hydrological models are important tools to assess the future water availability for catchments by simulating different scenarios. Before using the models for scenario assessment, they must be tested and validated for the target region. Only a few hydrological models have been applied in West African catchments. We therefore tested various models in the Ouémé catchment to evaluate their applicabilities to simulate future scenarios of water availability.

Hydrological modelling at the local scale

The physically-based model SIMULAT was applied at the local scale in a modified hillslope version (SIMULAT-H; Giertz, 2004; Giertz et al., 2006a). Using a reliable database (↗17), the model was evaluated in a multi-criteria validation using discharge, discharge components and soil moisture data. For validating discharge, satisfying results were achieved for dry (2001) and wet (2002) years (see Fig. 1 and Tab. 1). The main differences were observable at the beginning of the rainy season.

A comparison of the discharge components determined by hydrochemical measurements with the simulation revealed that the model simulated the ratio of groundwater fluxes to fast runoff components correctly.

Tab. 1: Quality measures of model validation, lower Aguima (16.5 km²).

	Q measured [mm]	Q simulated [mm]	model efficiency	R^2	index of agreement
proxy basin test	139.6	132.5	0.86	0.87	0.96
split sample test	45.5	47.4	0.82	0.82	0.95

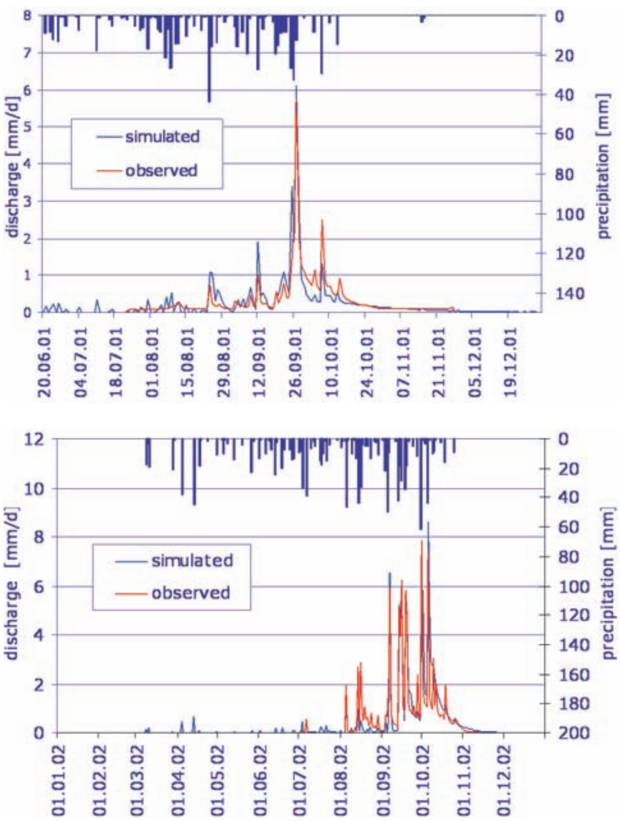

***Fig. 1:** Validation of discharge, lower Aguima (16.5 km²), 2001 and 2002.*

Discharge components were determined by geochemical measurements. For rapid runoff components (surface runoff and interflow), the simulated value was 69 %, while measurements indicated 73 %. The base flow was estimated at 27 %, while the simulation result was 31 %. In addition, the soil moisture dynamic was well represented by the model (Fig. 2).

Hydrological modelling at the regional scale

At the regional scale, the conceptual, distributed model UHP-HRU was applied (Giertz et al., 2006b). This is a conceptual model that takes into account all relevant hydrological processes like evapotrans-

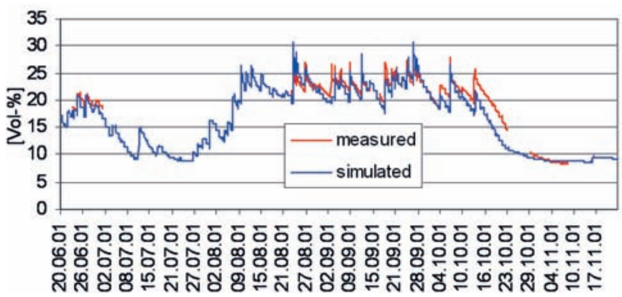

***Fig. 2:** Comparison of simulated and measured soil moisture for the upper soil layer of a Lixisol with woodland vegetation in Upper Aguima.*

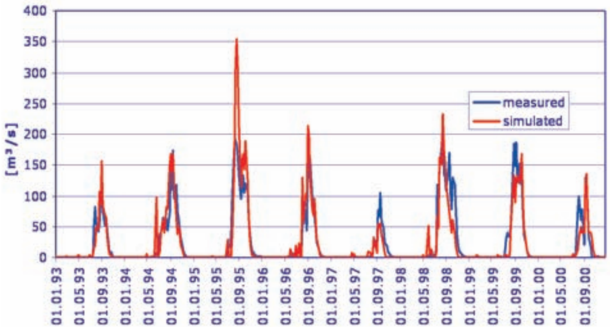

Fig. 3: *Validation of discharge, Térou-Wanou (3060 km²), 1993–2000.*

piration, surface runoff, interflow, percolation and groundwater recharge. The model is composed of three linear storages, root zone storage, unsaturated zone storage and saturated zone storage, which are linked by percolation and capillary rise. Potential evapotranspiration can be calculated with the Penman, Turc or Priestley and Taylor approaches. To compute surface runoff, the SCS (Soil Conservation Service) curve number approach was used.

UHP-HRU was successfully applied to different sub-catchments of the Ouémé river and validated against measured discharge. For most of the simulated catchments, good or satisfactory model results were obtained (Tab. 2).

After validating the model for different sub-catchments and years, climate and land use scenarios were simulated (↗16).

Tab. 2: *Quality measures of UHP-HRU application in the Upper Ouémé catchment (validation period).*

River, gauge	Simulated period	Model efficiency	R^2
Térou, Wanou	1993-2000	0.79	0.80
Térou, Saramanga	1998-2001	0.81	0.77
Térou, Igbomakoro	1998-2003	0.84	0.81
Aguimo	1997-2003	0.70	0.69
Donga, Pont	1998-2003	0.73	0.72
Donga, Affon	1998-2002	0.81	0.80
Ouémé, Beterou	1997-2000	0.82	0.75

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16

Assessing the Impact of Climate and Land Use Change on Future Water Availability in the Ouémé Catchment

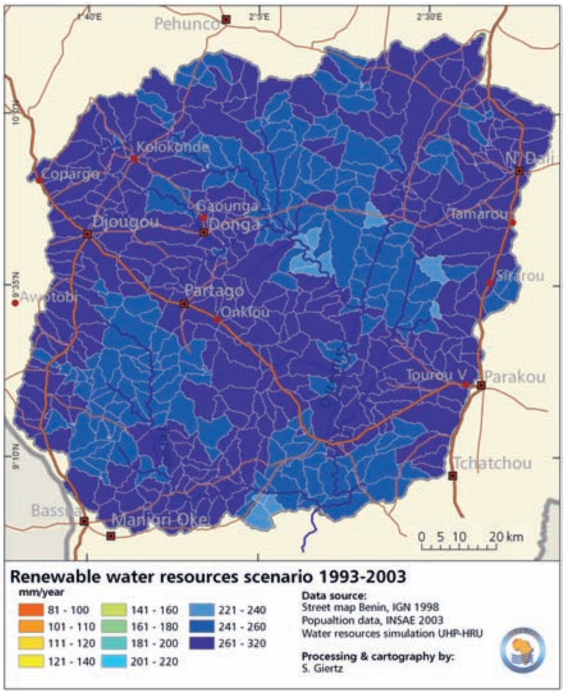
Simone Giertz

After a successful validation, the hydrological model UHP-HRU was used to simulate different climate and land use scenarios for the Upper Ouémé catchment. For the Ouémé-Bonou catchment, only climate scenarios were simulated as no land use change scenarios were available.

Scenario modelling approach
To assess the effects of climate and land use change on future water resources in the Ouémé catchment, we used an interdisciplinary modelling approach (Giertz et al., 2006).

In the scenario modelling process, the time variant input parameters are computed with other models. LUCC (land use and cover change) modelling is performed with the model CLUE-S (↗40). The climate scenarios are simulated with the regional climate model REMO on a 55 km grid. The model is nested into the General Circulation Model (GCM) ECHAM. In order to use the REMO results for hydrological modelling, we applied a statistical downscaling approach for rainfall data.

IPCC climate scenarios A1B and B1 were available. Scenario A1B describes a more globalized world with high economic growth, while scenario B1 is characterized by more sustainable growth.



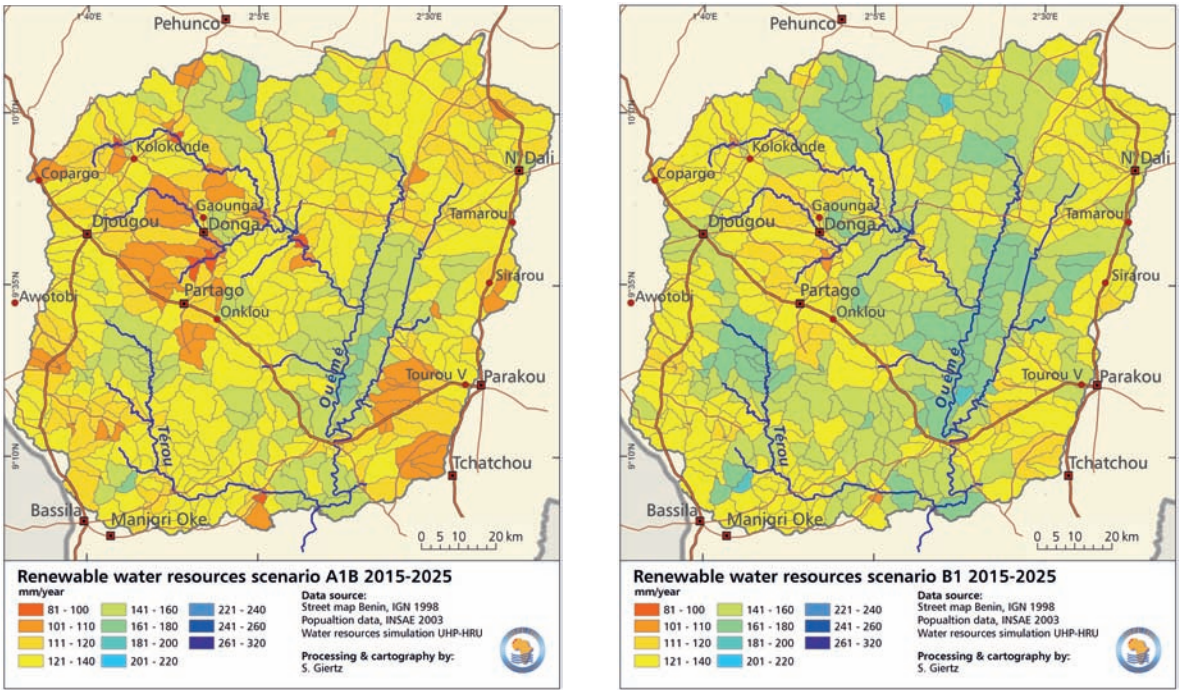


Fig. 1: *Comparison of renewable water resources as calculated for 1993–2003 (above) and for climate scenarios A1B (left) and B1 (right) combined with a land use scenario business as usual 2015–2025.*

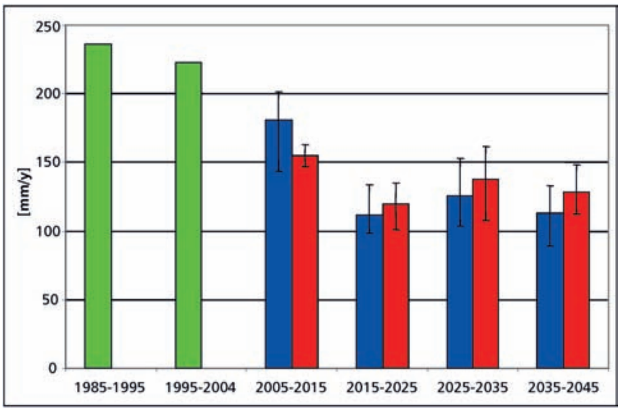


Fig. 2: Renewable water resources in the Ouémé-Bonou catchment for different decades, past (green) and future scenarios A1B (blue) and B1 (red).

For each scenario three ensemble runs were carried out with REMO. In order to take into account the variability of the REMO results, three model runs were performed for each scenario with the hydrological model, and the mean of the three runs taken as the result.

Combined land use and climate scenarios

For the Upper Ouémé catchment (HVO), we simulated combined land use and climate change scenarios. Both climate scenarios were combined with the land use scenario business as usual. Figure 1 compares the mean renewable water resources (river discharge and groundwater recharge) for the period 1993–2003 and the scenario A1B period 2015–2025. The scenario shows a strong reduction in available water due to a drop in rainfall and increased temperature. For scenario B1, the reduction in available water was less significant than for scenario A1B. While for the whole HVO mean water availability was about 262 mm/y for the decade 1993–2003, only 129 mm/y were simulated for A1B and 141 mm/y for B1 (2015–2025).

Climate scenarios Ouémé Bonou

The UHP-HRU model was also applied for the whole Ouémé catchment. As no land use scenarios were yet available, climate scenarios were calculated with constant land use.

Figure 2 shows the results of the climate scenario modelling. Like the results for the Upper Ouémé catchment, the amount of renewable water decreases for both future scenarios compared to past decades. The highest decrease is observable for the A1b-scenario, caused by an extreme decline in rainfall in the region. In the more sustainable scenario B1, the decrease in water resources is also significant compared to past decades, but less high than for A1B. The uncertainty bounds show the minimum and maximum of the three ensemble runs.

References

Giertz, S., Diekkrüger, B., Jaeger, A. and Schopp, M. (2006): An interdisciplinary scenario analysis to assess the water availability and water consumption in the Upper Ouémé catchment in Benin. Adv. Geosc., 9, 3–13.

17

Acquiring a Database for Hydrological Process Analysis in the Aguima Catchment

Simone Giertz and Gero Steup

In the first phase of the IMPETUS Project, most of the research activities concerning hydrology, hydrogeology, soil science, vegetation dynamics and agriculture were carried out in the Aguima catchment, which is located in the south of the Upper Ouémé catchment (see Fig. 1). This was chosen as the main test site of the project because it is representative of the geology, soil and vegetation of the area. As no hydrological data were available for the catchment at the beginning of the project, several measuring instruments were installed, and manual field measurements were taken in order to create an adequate database for a hydrological analysis (↗18).

Introduction

In order to analyse hydrological processes, measurements of discharge, soil moisture, soil suction and physical soil properties were carried out, mainly in two sub-catchments of the Aguima catchment (Upper Niaou and Upper Aguima), which have different land uses. In both catchments, climate data were obtained with automatic weather stations. Figure 1 shows the hydrological measuring sites of the Aguima catchment, and Tab. 1 summarizes the measuring activities in the Aguima catchment during the IMPETUS project.

Discharge measurements

Discharge measurements serve as a basis for hydrological analyses and for model validation. In the Aguima catchment, four water level gauges were installed in 2001, and another in 2002. The water level (measured with a floater; Thalimedes, company Ott, Germany) was recorded in 10 min. intervals by an automatic data logger. Discharge was measured at different water levels with the velocity-area–method using an electromagnetic flow sensor (Nautilus, company Ott, Germany). Using these data, the stage-discharge-relationship was determined for each gauge.

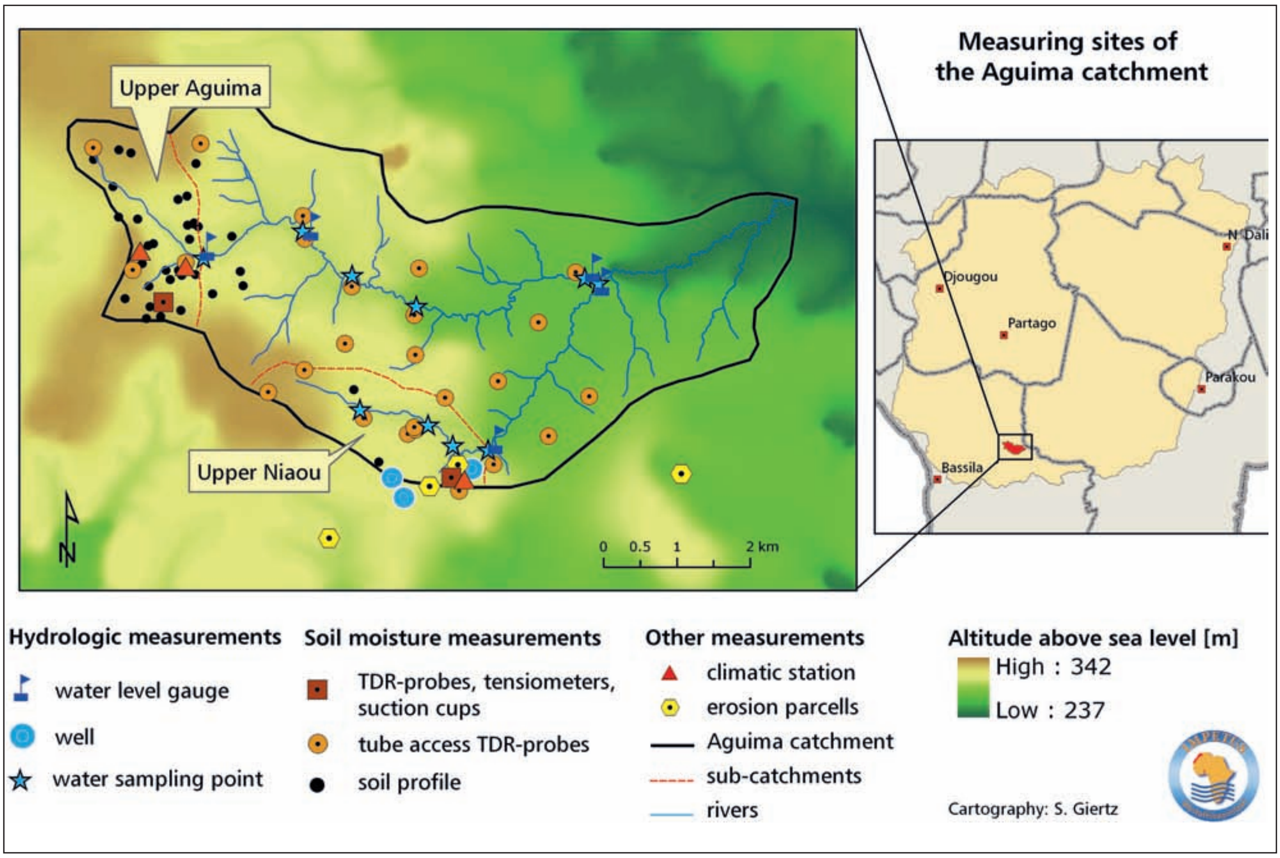


Fig. 1: Measuring sites of the Aguima catchment.

Tab. 1: Overview of measurements in the Aguima catchment.

Measured parameter	Sensor	Number	Temporal resolution	Period
Climate Data				
Precipitation	Tipping bucket rain gauge	3	10 min	June 2001–2007
Climate Data	Campbell climate stations	3	10 min	June 2001–2007
Surface hydrology				
Water level / discharge	Floater, electro-magnetic flow sensor	5	10 min	June 2001–2007
Electric conductivity	Automatic electric conductivity sensor	2	10 min	22. 08. 02 – 31. 10. 02
Surface runoff	Erosion plots	6	Event-based	Rainy season 2001 and 2002
Soil water dynamic				
Soil moisture, soil suction	TDR-probe Tensiometer	4 plots with 4 depth	10 min	June 2001–2004
Soil moisture	mobile TDR-probe	3 transects	weekly	March 2002–November 2002
Soil moisture	Tube access probes	35 tubes, 3–7 measuring depth	weekly	June 2001–2004
Soil physical properties				
Infiltration measurements	Double ring, single ring, hood infiltrometer	15 plots		Measuring campaign 2001–2003
Soil physical properties (K_{sat}, K_u, pF, bulk density)	Different laboratory methods	50 soil profiles		Measuring campaign 2001–2003

In order to determine the discharge components, conductivity probes were installed at the gauges of the Upper Aguima and Upper Niaou catchments in 2002. These data were used to analyse the discharge component of catchments with different land use.

Climate measurements

The density of climate stations in Benin is very low. As climate data are required for hydrological analyses and modelling, three climate stations were installed in the Aguima catchment. One station is located on a small hill (inselberg), and the others were installed in vegetated sites (savannah, maize field/fallow). All data were stored at 10 min. intervals.

Soil water dynamics

TDR-probes and tensiometers were set up on four plots with different land use (maize field, cotton field, dense savannah, sparse forest). The probes were installed at four depths (0–20, 30–50, 80–100 and 120–140 cm). The set–up of the measuring plots is shown in Fig. 2. In addition, 38 tube access probes were installed to measure the spatial difference in land use. The locations of these are shown in Fig. 1.

These data were used to analyse the soil water dynamics of the soil under different land use conditions and to validate the local hydrological model.

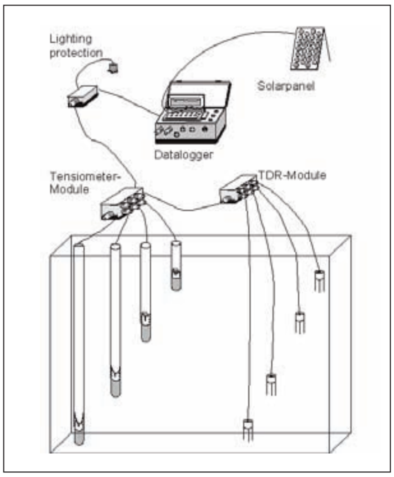


***Fig. 2:** Installation scheme of the soil water measuring plot.*

References

Giertz, S. and Diekkrüger, B. (2003): Analysis of the hydrological processes in a small headwater catchment in Benin (West Africa). Physics and Chemistry of the Earth, 28, 1333–1341.

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18

Analysing the Effects of Land Use / Land Cover Changes on the Water Cycle

Simone Giertz and Gero Steup

Land cover plays an important role in the water cycle. In the first phase of the IMPETUS project, the impacts of land cover / land use changes on the hydrological processes were analyzed in two sub-catchments of the Aguima: the upper Aguima catchment (3.2 km²), characterized by natural vegetation (mainly tree savannah), and the upper Niaou catchment (3.1 km²), which is dominated by agricultural land use. In both catchments, discharge, soil water dynamics and soil physical properties were measured for the analysis (↗ 17).

Impact of land cover on physical soil properties

Land cover has a major impact on the physical properties of soil. Measurements of in-situ saturated hydraulic conductivity with hood, double- and single ring infiltrometers were carried out on plots with different land use within the Aguima catchment. At least eight measurements were taken on each plot. The results (Fig. 1) show reduced saturated conductivity for cultivated plots compared to the plots with natural vegetation. This is mainly caused by reduced activity of the soil fauna on cultivated sites (Giertz et al., 2005), leading to a reduction of macropores in the soil, which have a major impact on the saturated conductivity.

In addition, saturated conductivity was measured for soil cores taken from different soil depths. The measurements revealed that the permeabilities of the sub-soil horizons of the dominant soil types (Plinthosol and Lixisol / Acrisol) are low, causing lateral sub-surface flow (interflow) in these soils (see Tab. 1).

Impact of land cover on river discharge

The comparison of hydrographs of the investigated sub-catchments (Fig. 2) shows higher discharge and higher peak discharge in the agriculturally used catchment (Niaou). The difference is particularly remarkable in the drier year of 2001 (see Tab. 2).

The main reason for the higher discharge volume and higher peak discharge is the increase in surface runoff on fields compared to natural vegetation. This is caused by a reduction in the permeability of

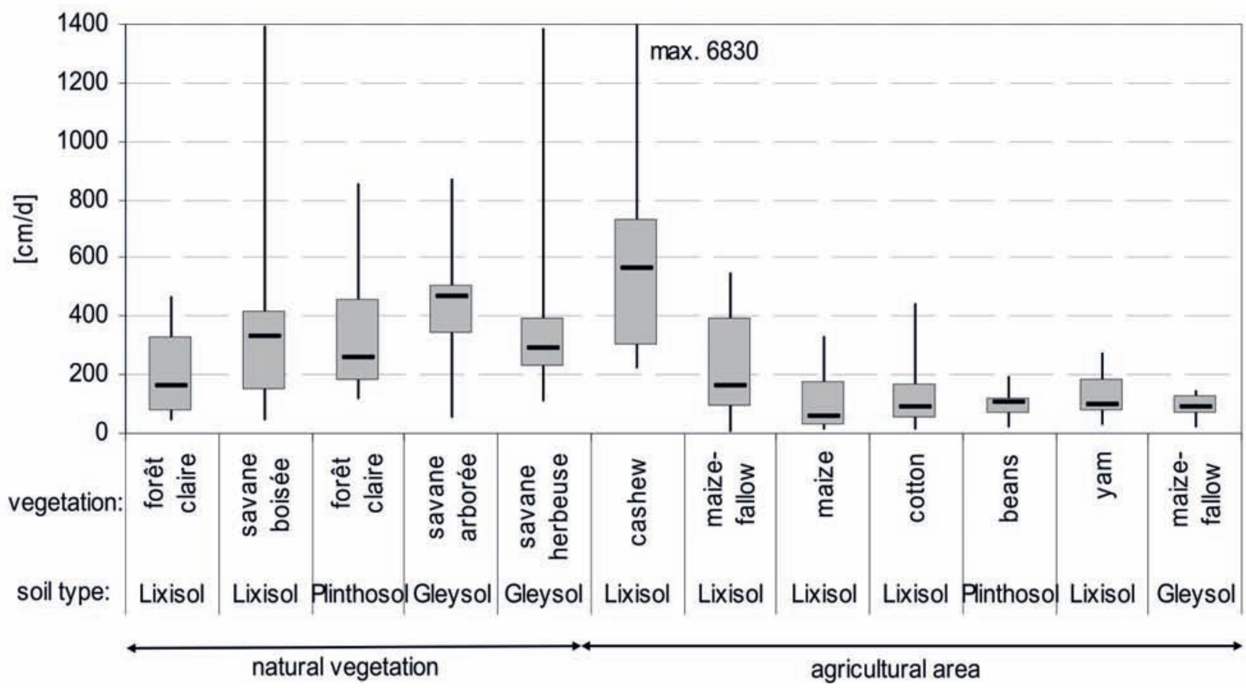

***Fig. 1:** Box-plot of in-situ saturated conductivity measured on different land use and soil types. Crossbar: Median, length of box: interquartile range, tails: minimum and maximum*

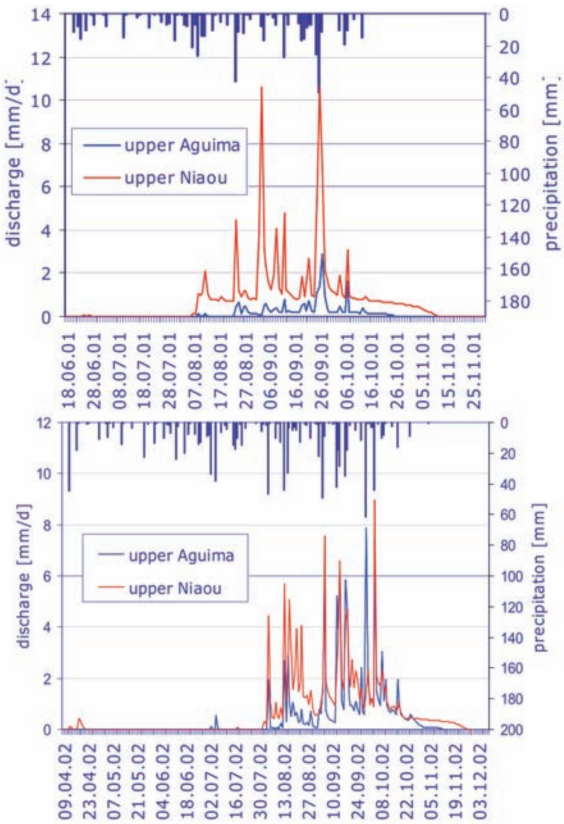

Fig. 2: *Hydrographs of the Upper Aguima and Upper Niaou catchments for 2001 and 2002.*

soil surfaces in fields, which was revealed by infiltration measurements on different land use and soil types (see Fig. 1).

Other reasons for the higher discharge volume in agricultural catchments are the decrease in evapotranspiration (due to lower vegetation density) and a decrease in soil water storage. This is caused by the reduction in soil thickness caused by soil erosion, which was shown by Giertz et al (2005).

The main hydrological processes, based on field measurements and observations, are summarized in Fig. 3.

References

Giertz, S. and Diekkrüger, B. (2003): Analysis of the hydrological processes in a small headwater catchment in Benin (West Africa). Physics and Chemistry of the Earth, 28, 1333–1341.

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Tab. 1: *Saturated conductivity of Lixisols in the Aguima catchment (laboratory measurements on soil cores).*

horizon	n	mean saturated conductivity [cm/d]	
		field	natural vegetation
Ah/Ap	64	17.17	64.85
E	46	30.89	33.21
Btc	45	55.81	112.98
Ct	38	13.02	24.46

Tab. 2: *Water balance in 2001 and 2002.*

	precipitation rainy season (June–October)	discharge upper Aguima	discharge upper Niaou
2001	609 mm	23 mm	136 mm
2002	820 mm	109 mm	160 mm

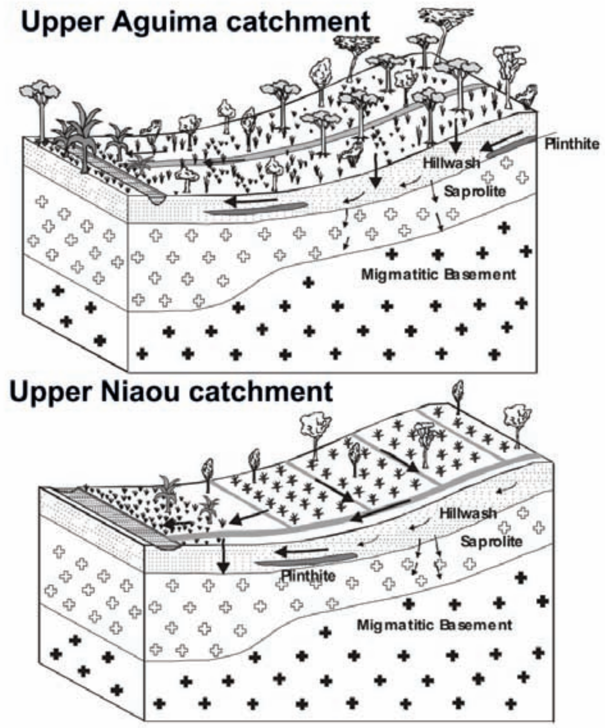

Fig. 3: *Hydrological processes in two sub–catchments of the Aguima.*

19 Drinking Water Supply in Benin

Moritz Heldmann and Martin Doevenspeck

Drinking water in Benin is taken from very different sources, ranging from open surface water to tap water. A state-owned service, the SONEB (Société Nationale des Eaux du Bénin), provides tap water in the cities, while the *DGO (Direction Générale de l'Eau)*, another public service, is responsible for water in rural areas, where no main supply exists. Limited access to safe drinking water and spatial disparities in supply still characterize the water situation in Benin.

Drinking water supply in Benin

Data on water supply at a national scale is available through the 2002 national census (INSAE, 2003). Although the data do not reveal the complexities of the drinking water situation, which is characterized by the use of various sources by the same users at different periods and places, it gives an overview about the drinking water supply in Benin. During the census, heads of household were asked about their principal drinking water source. Nevertheless, though the emphasis was on "the principal source", it is highly likely that other sources of drinking water beside the ones mentioned are used by the same households.

However, spatial disparities in the supply situation become evident when mapping these data at the level of Benin's *Arrondissements.*

Mostly safe drinking water sources

The different types of drinking water sources can roughly be divided into mostly safe and mostly unsafe sources (Tab. 1 and 2, ↗21). Only 54.5 % of Benin's households drink predominantly safe water. In rural areas, this refers mainly to pumps, cisterns and drinking fountains (↗21). Tap water, considered the safest water source, is only available in the cities and thus in a very small part of the country (Fig. 1).

Even in the cities, many people do not have their own tap water supply, but instead buy water from people who are connected to the mains. There is a growing informal market for tap water around the urban centres in Benin.

Tab. 1: *Housholds using mostly safe drinking water (INSAE, 2003)*

tap water (household connection)	externally purchased tap water	drinking fountain	pump	rainwater collection
9.8 %	21.3 %	5.7 %	15.3 %	2.4 %
54.5 % (of all household heads)				

Mostly unsafe drinking water sources

Open water sources like rivers, ponds and wells can be regarded as water sources that are likely unsafe: 45.5 % of Benin's households mainly use these unsafe water sources. Even modern wells are often contaminated (↗21).

Besides some areas in Southeast Benin, such as the lower Ouémé valley, unsafe drinking water is a major problem in other parts of the country. For a significant number of households, surface water from rivers, small ponds or water holes still constitutes the principal drinking source. There are several reasons for this situation, but in many villages, water pumps or even modern wells are either absent or do not bear enough water across different seasons.

Tab. 2: *Housholds using mostly safe drinking water (INSAE, 2003).*

protected well	unprotected well	surface water (river,pond)	other water	not determined
8.2 %	22.3 %	13.0 %	0.7 %	1.3 %
45.5 % (of all household heads)				

References

INSAE (2003): Troisième Recensement Général de la Population et de l'Habitation. Cotonou.

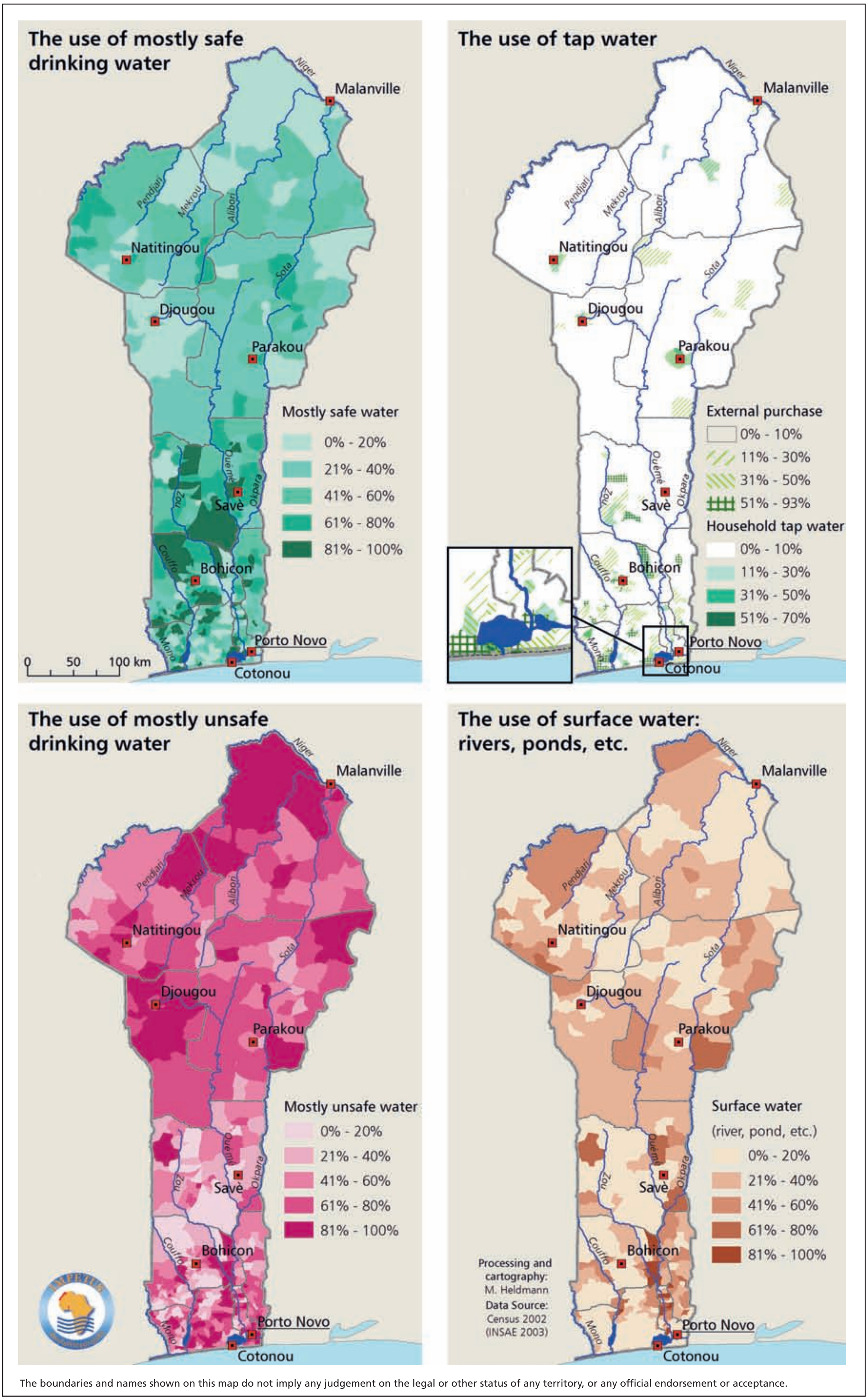

Fig. 1: Drinking Water Supply in Benin

Drinking Water Supply in the Upper Ouémé Catchment

Farouk Mazou, Alexandra Uesbeck and Rainer Baginski

Rural African areas reveal a high incidence of infectious diarrhoea and other gastrointestinal diseases that may be due to unsafe drinking water supplies. In Benin, two of five households do not have access to safe drinking water. Bacteriological and virological analysis of different water sources have been performed to gain insight into the quality of drinking water in the region between the cities of Parakou, Bassila and Djougou.

Different types of water sources

As a first step in the estimation of waterborne bacterial and viral disease contaminants, all water supplies in the triangle between the cities of Parakou, Bassila and Djougou in the Upper Ouémé Catchment were located. GPS-data on the sources have been taken, the constructors of wells and pumps were registered and the surroundings of the water sources were documented. The resulting database of more than 1200 fresh-water sources (Fig. 5) reveals that 89 % of all sources used as drinking water supply are open wells (traditional and modern), representing the most frequent type of drinking water source. So called "marigots" – ponds and lakes – represent 4.5 % of sources, while boreholes with pumps represent only 5 % of the registered water sources. Some villages do not even have access to safe water from boreholes with closed pump systems at all. Water from wells that are either open at the land surface, or do not have water-tight casings or caps can be easily contaminated by bacteria or viruses through inundation or infiltration by flood waters or by surface runoff. Another way contaminants can enter from the surrounding area into a well is via so called "puisettes" – black buckets – which are used to scoop water from wells and are not stored under appropriate hygienic conditions.

Fig. 1: *Traditional well*

Fig. 2: *Modern well*

Fig. 3: *Small lake, traditionally called "marigot"*

Fig. 4: *Hand pump*

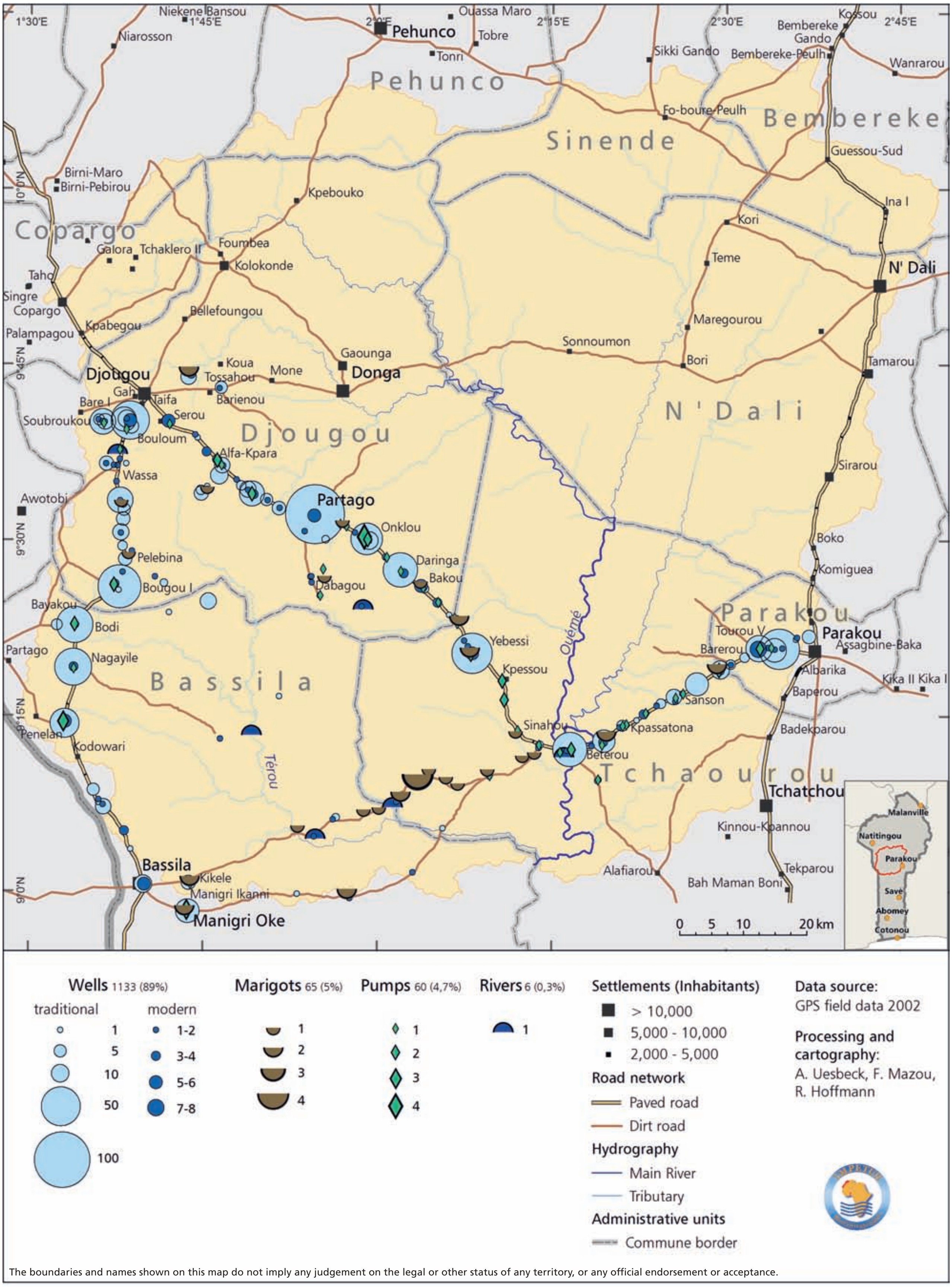

***Fig.** 5: Types of drinking water supply in the Upper Ouémé catchment.*

21

Bacteriologic Analysis of Drinking Water Sources in the Upper Ouémé Catchment

Alexandra Uesbeck, Rainer Baginski and Farouk Mazou

Worldwide, more than 1.2 billion people have no access to improved water supply and as consequence, over 2 million people, most of them children, die every year of diarrhoeal disease linked to inadequate water supply and hygiene. Several bacterial pathogens can cause water-borne infectious diseases such as typhoid fever, gastroenteritis or cholera. Since the bacteria levels in drinking water are not regularly controlled by the national water authorities, this study aimed to analyse the water quality of different water sources in rural Benin.

Waterborne pathogenic bacteria

Water from different drinking water sources in the Upper Ouémé catchment was sampled to determine whether it contained infectious agents. Bacterial pathogens like *Yersinia sp.*, *Vibrio cholerae*, Salmonellae, Shigellae and *Clostridium* species can cause waterborne infectious diseases such as enteric and typhoid fever, gastroenteritis, dysentery, septicaemia or cholera, which are a major problem for children, the elderly and undernourished people.

The results of bacteriologic analysis reveal that about 70 % of all open surface water sources, such as water holes, and various types of wells, are contaminated with faecal flora (like *E. coli* and coliform bacteria). The presence of these faecal bacteria in drink- ing water indicates a source of contamination by which other pathogenic bacteria as *Vibrio cholerae* or typhoid *Salmonellae* might enter the water.

Of all the examined drinking water sources, 8 % are contaminated by non-typhoid Salmonella enterica ssp. enterica (Fig. 1). Enteritic Salmonellae are widely distributed in the environment, with an origin in the intestinal tract of human beings and a wide range of animals, including poultry, cows, pigs, sheep, birds and even reptiles. The pathogens typi-

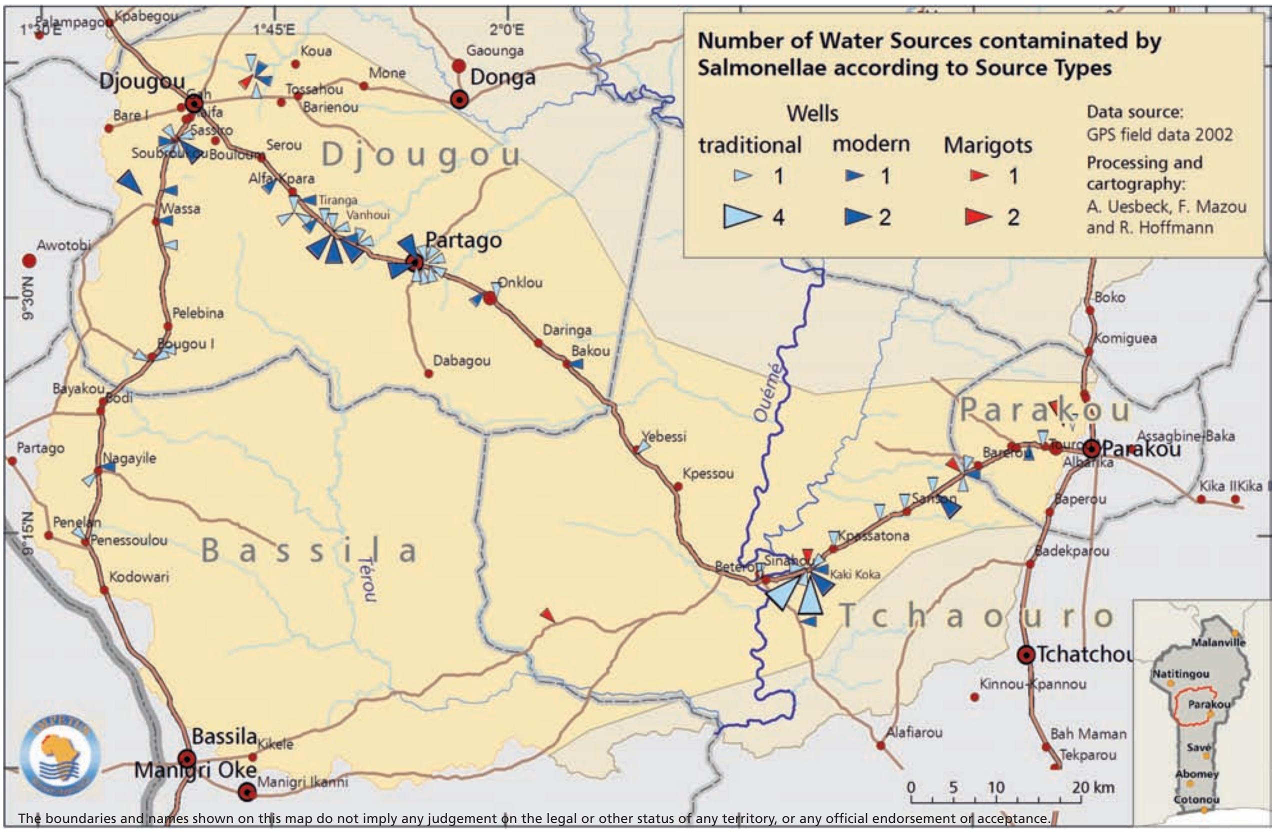

Fig. 1: Water sources contaminated by Salmonellae in the HVO (2005).

cally gain entry into water systems through faecal contamination from sewage discharges, livestock and wild animals. In contrast, water samples taken from closed borehole-systems with pumps were free of bacterial contamination.

Detection of bacteria in water samples

Bacterial contaminants were isolated from water samples, cultivated on selective media, and identified biochemically in our laboratory in Parakou. Further identification was performed by serological, biochemical and genetic methods at the Institute of Medical Microbiology, Immunology and Hygiene in Cologne (IMMIH).

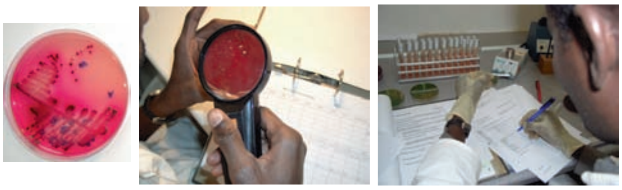

Fig. 2: *Salmonellae on selective nutrient agar plate, blood agar and biotyping of bacteria.*

Case study in the village Kaki Koka

In the village Kaki Koka, Salmonellae were detected in six drinking water sources out of a total of 22 (see Fig. 3). In order to find a relationship between infectious diarrhoea and contaminated water, stool samples of 357 inhabitants who consumed water from these sources were examined. The analysis revealed that 2 % of the inhabitants are carriers of Salmonellae. To assess their actual health status and socio-medical habits, questionnaire data were collected in Kaki Koka. They show a high prevalence of diarrhoea and other gastrointestinal diseases.

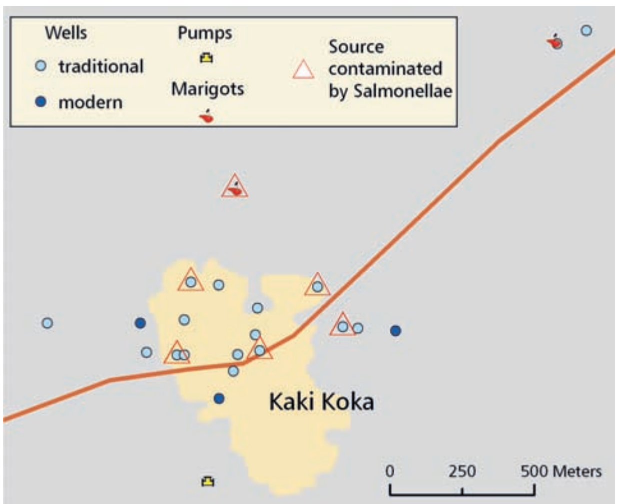

Fig. 3: *Contaminated water supplies in Kaki Koka, 2004.*

Sanitation and water disinfection

In cooperation with the local hygiene service (SHAB "Service de l´Hygiène et Assainissement de Base") the effect of water disinfection with chlorine was examined. Water samples were taken and analysed before, directly after, and several weeks after disinfection. The first results showed that only a few days after successful disinfection, most wells show new bacterial contamination. This recontamination may be caused by so called "puisettes", which are used for collecting water and often come in direct contact with animals and faeces after use.

In cooperation with the Swiss project HELVETAS, the effect of the restoration of open wells on water quality was investigated: traditional wells in 15 villages have been converted into closed pump systems by installation of a drill stem and by covering the upper opening in order to prevent contamination. Concurrent hygienic monitoring of these pumps conducted by IMPETUS revealed that even after several months, the level of faecal flora was significantly reduced (see Tab. 1).

Tab. 1: *Hygienic monitoring of well restoration.*

Village	Contamination before conversion	Contamination after conversion
Sakarou	20 *E. coli*/ml > 500 coliform bacteria/ml	0 *E. coli*/ml 5 coliform bacteria/ml
N´Dali	33 *E. coli*/ml > 500 coliform bacteria/ml	0 *E. coli*/ml 0 coliform bacteria/ml
Kpari	0 *E. coli*/ml > 500 coliform bacteria/ml	0 *E. coli*/ml 5 coliform bacteria/ml

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22

Viral Contamination of Drinking Water Sources

Jens Verheyen and Herbert Pfister

Viruses related to diarrhoea or hepatitis have a major impact on public health in developing countries and can be found in all kinds of environmental samples. We established a method to detect and quantify the concentration of different viruses in water samples, which was validated by appropriate controls. The range of detectable viruses include Adeno-, Entero-, Hepatitis-A-, Noro- and Rotaviruses.

Introduction

Waterborne diseases caused by viruses, such as severe diarrhoea or hepatitis, are widespread in developing countries and have a substantial impact on public health. Virus detection in environmental samples could therefore improve hygienic conditions and could save lives of the dependent population. As viruses do not replicate outside a host, the amount of viruses in the environment is normally low and decrease with time after contamination. However, even a few viruses are sufficient to infect humans and cause a great variety of diseases. A method for virus concentration is therefore needed to reveal even low levels of viruses.

Methods

The quality of drinking water sources was investigated by analysing wells in the triangle between the cities of Parakou, Bassila und Djougou in the Upper Ouémé region for viral contaminations. A method of virus concentration was established before testing for different viruses (Adeno-, Entero-, Hepatitis-A-, Noro- and Rotaviruses). Ten liters of water samples were filtrated with special filters in Benin, and were then sent for further investigation to the Institute of Virology in Cologne, Germany.

Validation

The validation of this method revealed that 10 l water samples spiked with 1 ml of reference Adenovirus suspension corresponding to the concentration of virus shed by symptomatic patients could be detected. Even contamination of water with adenovirus-stock suspension 1:1000 diluted could be revealed by this method. Enterovirus in positive controls (1 ml enterovirus suspension + 10 l water) could also be consistently detected.

Results

We found viral contamination in about 8 % of the drinking water sources that were investigated. The majority of detected viruses were Adenoviruses. These viruses lead to a great variety of symptoms in infected patients. Adults and children could develop diarrheic diseases after infection. Whereas diarrhoea in adults is temporary but compromises daily work, diarrhoea in children is a life-threatening event.

One major challenge is to disclose risk factors for viral contamination of drinking water sources. This effort is still in progress with the cooperation of physicians, biologists, ethnologists, geologists and meteorologists.

Perspectives

In cooperation with the Children University Hospital in Parakou, we analysed the cases of diarrhoeic diseases with a viral origin of symptoms, namely Rota- and Adenoviruses, that were treated at the hospital. The number of cases could help to estimate the burden of viral infections for public health and could be used as a indicator of effectiveness following attempts to improve hygienic conditions.

As Adenoviruses are suitable indicator viruses for viral contamination of drinking water sources, modifications of the validated method should enable detection of severe viral contamination in the IMPETUS laboratory in Parakou.

Conclusion

Viral contamination of drinking water sources in the upper Ouémé valley occurs and influences public health. An improvement of hygenic conditions could reduce the burden of viral infections.

Fig. 1: Sample collection from a pump

Fig. 2: Sample filtration for viral analysis

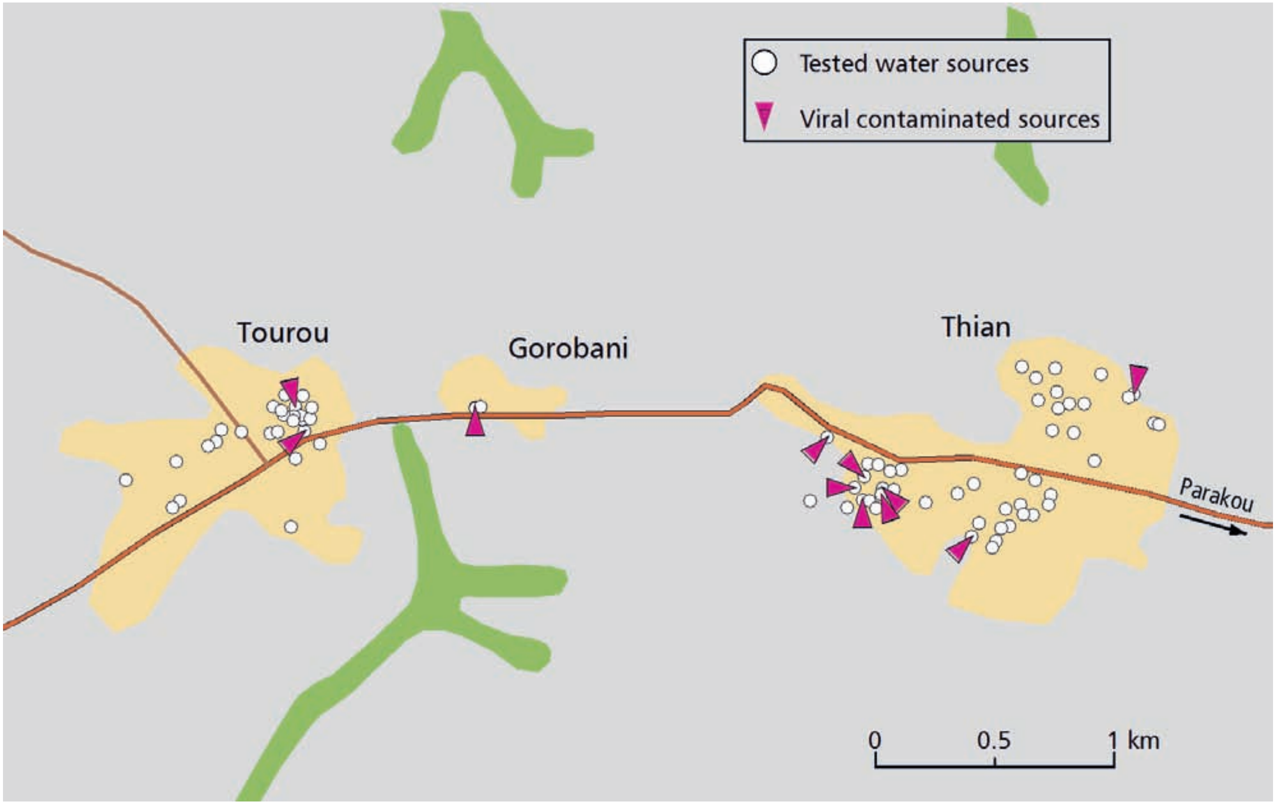

Fig. 3: Distribution of Adenovirus positive and negative drinking water sources of the villages Gorobani, Thian and Tourou in Jun/July 2004.

23

Water and Health

Thamar Klein

Water is intimately linked to health in many ways. Health risks arise from waterborne diseases, waste water, tropical diseases spread by vector insects (e.g. mosquitoes and black flies) whose larvae depend on water, as well as from foodborne diseases where contaminated water is used in the preparation of food. The disparities in sanitation and access to potable water, however, are vast between urban and rural areas in Benin.

The Right to Water

Benin is still far from providing safe drinking water for everybody. The "[…] right to water […] in the General Comment N°15 of the International Covenant on Economic, Social and Cultural Rights […] entitles every human being to sufficient, safe, accept- able, physically accessible and affordable water for personal and domestic use. The right to water includes the right to sanitation" (Dubreuil, 2006, p. VI). Even though Benin had already approved of this right, at least for children, in 1990 through the ratification of the African Charter on the Rights and Welfare of the Child (Smets, 2006, p. 13), adequate sup- ply of safe drinking water and adequate sanitation for everyone are not yet available. Water scarcity in Benin is, however, mainly a temporal, spatial, and economic affair. The rural Beninese population in the central and northern parts of the country is especially affected by it.

Access to potable water

In fact, access to safe drinking water is quite limited in the rural areas (↗19) of the Ouémé catchment. Here, mainly wells and marigots (water holes) as well as pumps constitute the main sources of water.

Table 1 is derived from data of a regional survey carried out in 2004 by Hadjer, Klein and Singer in the departments Donga and Borgou – with a total of 839 individuals being interviewed.

The risks for wells and marigots to fall dry during the dry season is high and the water quality poor, as a high percentage of these water resources is contaminated with faecal flora (↗21).

Marigots are a major source of such infections as hepatitis, amoeba, cholera, and typhoid fever. In addition, water may be contaminated when it is stored.

Most water containers are cleaned very regularly (Klein 2005, p. 178). However, once they are contaminated most local cleaning procedures are not able to disinfect them (see Fig. 2). Moreover, there are numerous ways by which water becomes contaminated with pathogenic micro-organisms in the containers (e.g. dirty hands of children getting a sip of water and animals trying to drink out of the containers), even though women try to protect the reservoirs carefully.

Tab. 1: *Obligation to drink water from marigots: percentage of inhabitants, n = 839.*

Municipality	always	dry season	during fieldwork	never
Tchaourou	25	11	1	63
Copargo	23	15	1	62
Djougou	18	7	–	75
N'Dali	6	5	–	89
Ouaké	6	2	–	92
Bassila	5	11	–	83
Parakou	3	–	1	97

However, it is not only the water quality but also the lack in quantity that poses a threat to the rural population. In a comparative long-term study carried out between August 2001 and January 2002, comprising a sample of 40 households in four villages and one small town, the average water consumption at the sites investigated was 18.7 liters. This is already below the "Per Capita Water Supply Standard" of 20 liters (l/p/d) put forward by the World Health Organization for villages (WHO,

Fig. 1: *Marigot*

Fig. 2: Cleaning of Water Container

2003). In the dry season, the mean per capita consumption shrank even further, to 15 liters, with an absolute minimum of only 5 liters (Hadjer et al., 2005) as the local resources partially ran dry.

Waterborne diseases are not only transmitted by water consumption or poor food – and water sanitation practices, but also by mosquitoes and black flies (e. g. malaria, filariases, and onchocerciasis also known as river blindness), which make use of e. g. sewage as a breeding ground.

Fig. 3 & 4: Sewage

Women, Health Care and Livelihood

Not only scarcity, but also lack of water quality increases women's burden. Besides taking the strain of fetching water they also bear the burden of nursing the sick and covering health expenses.

Women and men in rural Benin operate with distinct budgets. Spousal pooling of financial resources in health related matters is not the norm and is usually only agreed on in cases where the person responsible for financial support is not able to do so. Even though men are regarded as the decision makers and financiers of health treatment in severe (and thus potentially expensive but also more infrequent) cases, men spent exactly one third less on the health care of their children than their wives (c. f. Klein, 2007). Rural men's income is seasonal, whereas women's income varies less seasonally as they are merchants or manufacturers of goods (e. g. soap, oil, shea butter). Therefore, their budget contributes substantially to health care. Their loss of income due to nursing the sick has to be considered as a further important aspect.

Summary

Safe water and adequate sanitation increase the individual well being and improve economic productivity. Preventing and reducing water-related diseases helps to alleviate poverty.

With an increasing scarcity of water and a decreasing quality of water, however, infant mortality as well as cases of severe infection (including that of livestock) will rise. The resulting circumstances e.g. higher work loads for the remaining healthy members of society, loss of livestock, and a higher financial burden due to treatment fees, enhance the vulnerability of the individual, household, and society.

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Regional Survey: Economic Dependence on Water

Kerstin Hadjer

Water constitutes an integral component of human livelihood security. Many people's economic activities in central Benin depend on the utilization of water. However, access to potable water is not evenly distributed. Numerous people are forced to purchase supplementary water or to drink non-potable water. Its consumption threatens the health of the population resulting in sick leave and loss of working potential.

Water access and purchase of water

Similarly to neighbor states, central Benin is characterized by a pronounced dry season and very heterogeneous conditions of water access. Difficult water access situations contribute to the lack of water supply in many rural places.

According to results of the statistically representative regional survey (↗52), a quarter of the population depends on water from waterholes (marigots), therefrom 63 % all season.

Approximately 40 % of the population depends on the additional purchase of water, which constitutes 17 % all year round. For instance, in the urban district of Parakou, 90 % of the informants stated that they spent money on water (Fig. 1). What are the reasons for purchasing additional water?

Water as a productive good

Apart from purchasing water for domestic needs, a third of the interviewed population requires water for productive activities. As shown in Fig. 2, 70 % of the respondents in the two communes, Tchaourou and Ouaké, depend on water economically.

In contrast to agriculture, water is needed frequently in horticulture where a quarter of the 513 interviewed farmers are engaged (22 % women,

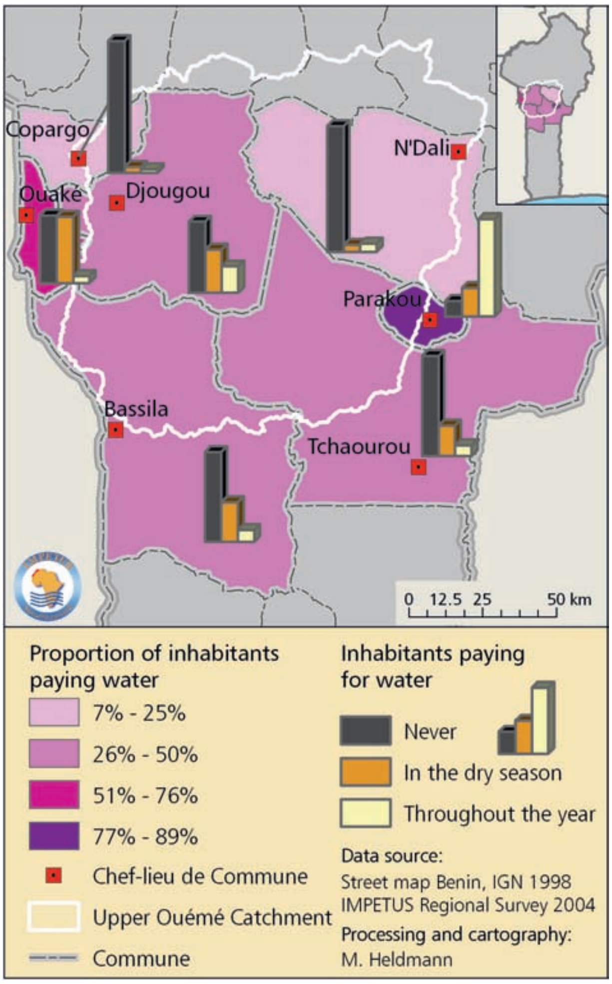

Fig. 1: *Purchase of water.*

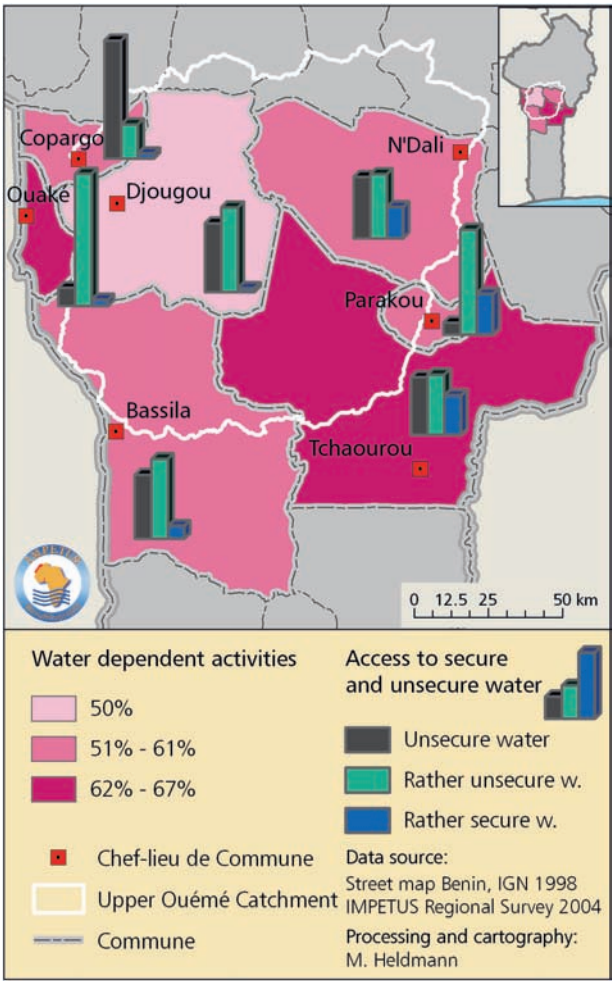

Fig. 2: *Economical activities depending on water.*

Fig. 3: Women collecting water

78 % men). Women, in particular, depend on the additional purchase of water due to transformation activities, e.g. further processing of agricultural products into meals and beverages. Activities less dependent on water are, for example, crafts.

Attention should be paid to the common risk strategy of economic multitasking, its seasonal dependency on water access, and the degree of rentability in the case of the additional purchase of water. A common strategy is the practice of horticulture in the rainy season and trade in the dry season. Furthermore, many respondents realized parallel multiple activities. For instance, a woman produced beverages and infrequently sold shoes. In times of water shortage, the trade serves her as an alternative income source.

All in all, 57 % of all acquired economic activities depend on water. Almost 34 % of activities need a lot of water in regular intervals. The economic dependence on water is distinctly higher in rural areas.

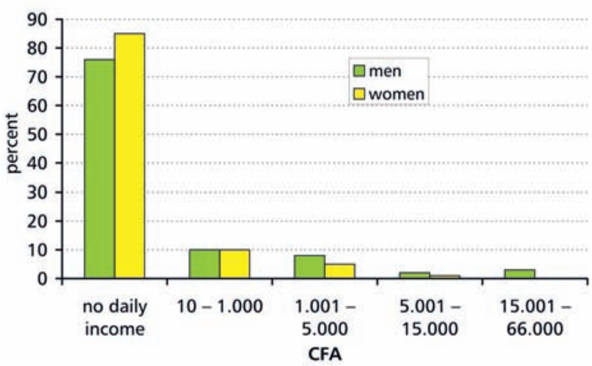

Fig. 4: *Daily Income (n = 839, 2004)*

Focussing on vulnerability

The situation with the poorest access to water exists in the north-west of the survey area (*Communes* Copargo, Djougou, Ouaké).

At the same time, 58 % of the population takes part in activities depending on water. This region is particularly at risk in the case of drought or a non-differentiated water-taxation: with the decline of available water, economic capacities diminish and vulnerability increases.

Financial background

On the assumption that the average per-capita consumption amounts to 18.7 litres (Hadjer et al., 2005), the maximal costs for water from pumps will equal approximately 1,000 CFA per month/adult. As figured below (Fig. 4), the mean value of a regular daily income constitutes 1,200 CFA, thus earning structures allow the purchase of additional water.

However, in reality men gain larger amounts over longer time intervals, whereas women earn small amounts on a regular basis. Fetching water is traditionally a female domain. In times of low income, the need to purchase water regularly can lead to social strife and conflicts because the responsibilities for paying for water are unresolved.

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25

Water Consumption Embedded in its Social Context

Kerstin Hadjer, Thamar Klein and Marion Schopp

Daily water consumption depends on many factors, among them seasonality, size of household, access to resources and the social context. In an interdisciplinary case-study for the *Commune* Donga, a marked heterogeneity in water access is documented. In some cases, the per capita consumption is much lower than the minimum standard of 20 litres set by the WHO.

Research site: Commune Donga

The unimodal rainfall distribution in the Upper Ouémé is a major factor that influences farming and use of resources, resulting in wider variations of water consumption throughout the year. The *Commune* Donga (central Benin) was studied in more detail with respect to the availability, quantity, and quality of water over a longer period.

Methodological design

An interdisciplinary micro-level study, covering a period of six months, was conducted between August 2001 and January 2002. The sample size comprised 40 households in four villages (Bougou, Dendougou, Pélébina, Sérou) and one town (Djougou). The households were visited once every month with the help of twenty assistants. Local assistants were chosen to minimize disturbance of the observed families. All water-related activities were correlated to socio-economic data of actors, including guests of the households.

The per capita water consumption follows the definition set by the United Nations: "Domestic consumption of water per capita is the amount of water consumed per person for the purposes of ingestion, hygiene, cooking, washing of utensils, and other household purposes including garden uses. Where it is customary for domestic animals to be kept at or in the living environ their needs are also included in the assessment" (United Nations, 2003).

Heterogeneities in water access

The situation of water access is very heterogeneous. Villages with many wells (e.g. Bougou) lie in close proximity to villages in which all inhabitants have to share a minimum of public wells (e.g. Pélébina). This heterogeneity is inter alia due to very different geological and soil conditions. In Pélébina, e.g., wells collapse easily, if not constructed at a high technical standard with respective expenditures.

In the middle of the dry season in particular, the distances to the wells may change considerably for each household when some wells dry out. The access conditions of households can be classified as in Tab. 1. In each of the studied villages, there are households that fall into the WHO's category of "no access" during the dry season.

Seasonal disparities and social aspects of water consumption

The average per capita consumption of households investigated is 18.7 liters. If one considers consumption by visitors (5 %), the value is reduced to 17.2 liters per person per day. The lowest consumption was found during the dry season (5.2 l) in Dendougou. Overall, consumption in the 40 households declines steadily during the transition from the rainy to the dry season (Fig. 1).

The discrepancy between national estimated consumption (19.5 liters in rural households, set by Gleick, 1992) and investigated households is caused largely by the great influence of the following indicators: seasonality, size of household, and access to resources. In urban areas, water consumption relates not only to differences in the quantities of water consumed and its purposes, but a marked role is also played by the differing consumption of poor and wealthy households. While, on average, rich households use twice as much water as poor households (21.9 l vs. 11.2 l), the mean values for poor and rich households in the villages are very close (16.8 l vs. 15.6 l). Here, poor and rich families have the same, limited access, so that prosperity does not emerge

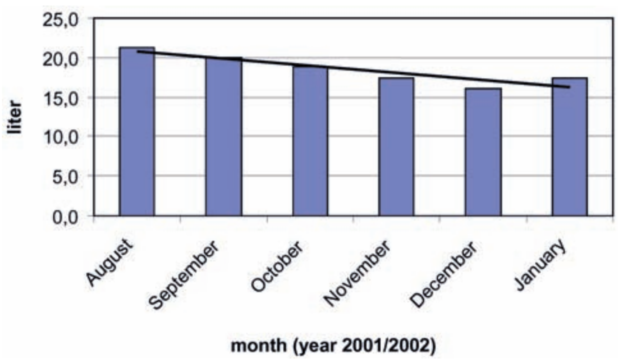

Fig. 1: Per capita water consumption in rural areas (year 2001 and 2002, n = 720 persons).

Tab. 1: Service level in the settings investigated.

Service level setting	Djougou	Dendougou	Sérou	Bougou	Pélébina
No access (More than 1 km or 30 min round trip)		X			X
Basic access (Within 1 km or 30 min round trip)	X	X	X	X	X
Intermediate access (Water provided on-plot through at least one tap)	X				
Optimal access (Supply of water through multiple taps within the house)					

as a significant factor influencing water consumption. In towns, the water consumption of wealthier households increases due to the ownership of more possessions and associated activities such as car washing.

An interesting social aspect is that despite the availability of tapped water in Djougou, well water is preferred by many. This was explained by the study participants to result from excessive costs for piped water and its poor taste. Piped water tastes of chemicals and the connections are often "tapped," thus leading to exorbitant bills; and not least, the water comes from a dammed lake, half of which is said to contain numerous dead bodies and spirits, and is therefore regarded by many inhabitants as unsuitable for consumption.

Looking at the indicator "religion", it was found that Moslem's consumption of water for religious washing rituals amounted to 3.7 %. In the strongly Islamic village of Bougou, almost 7 % of total water consumption was used for religious washing (maximum value), while in Dendougou it was only 1.7 % (minimum value).

Although drawing water is a female domain, 8 % of the total water quantity was collected by males. For a detailed analysis, see Hadjer et al. 2005.

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Water Demand at the Household Level in Benin

Marion Schopp and E. Adams

Benin - with an available fresh water quantity of 2.938 m³ per capita per annum - does not belong to the "water-stressed" or "water-scarce" countries of the world (PAI, 2008). However, access to safe water varies strongly between the dry and rainy seasons, as well as between rural and urban areas, which are caused by differences in technical and financial potentials and hydro-geological conditions. Therefore, it is necessary to analyse water supply and water demand within the local (urban / rural) context.

Investigation area and applied methods

On the assumption that information about water use should be taken from observations and measurements instead of from questioning only, two surveys were carried out in different regions of Benin.

Initially, an interdisciplinary study was carried out in four villages (Sérou, Dendougou, Pélébina, Bougou) and one city (Djougou) in the Upper Ouémé region in Middle Benin.

Afterwards, a representative survey was conducted in the cities of Parakou, Tchaourou, Djougou, Bassila, Savé, Glazoué, Klouékanmé, and Sô-Awa.

The surveys took place from December 2004 to February 2005 and included nearly 1200 households. The purpose of this representative analysis was to classify all the urban systems according to a newly developed water index. This index shows the measured water consumption (delivered water quantity) by SONEB and contains the quantity of water connections. The aim of this research was to examine water consumption at the urban household level and to identify the water sources used in the rainy and the dry seasons. In addition to determining the size of the household on a monthly basis, all water bills from January 2004 until December 2004 were collected.

Results

In the scope of the interdisciplinary analysis, two hypotheses were examined:

1. The water consumption is a linear function of the size of households.
2. There is a correlation between the age of household members and water consumption.

The calculations of reference values were based on two metric criteria: mean size of the household and mean age of the household members.

There is a high correlation (0,726), significant at the 1 % level, between water consumption and size of household, but no significant correlation concerning water consumption and age of the house-hold members.

In addition, highly seasonal water consumption levels could be observed. The average water consumption of 20.9 l / d / capita in the rainy season was much higher than in the dry season with 16.1 l / d / capita. The results indicate that the WHO standard of 20 litres is not reached in several regions (see Fig. 1).

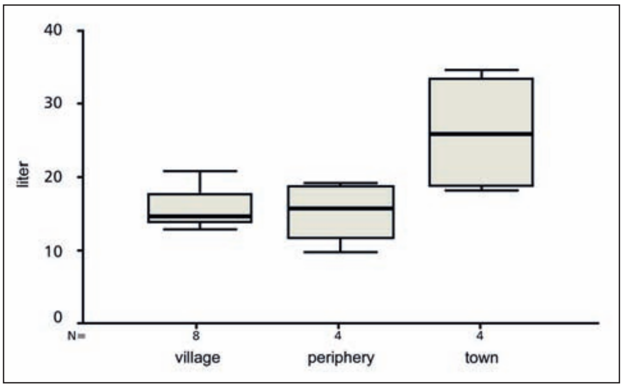

Fig. 1*: Water consumption according to access to water (town, periphery, village).*

According to results from a questionnaire in 2001 / 2002, which was applied to 90 women in the rainy and the dry seasons in rural and urban households, water shortages are regarded as a natural consequence of the climate (seasonality). Even though there is not enough water available for the population, especially in rural areas, this is for many families no reason to emigrate. This can also be explained by personal reasons such as social aspects (being close to families) or being a home- or a landowner.

Tap water has become more and more important for the population of Benin. Figure 2 confirms this for the eight towns in this analysis.

In contrast to rural water consumption, urban tap water consumption is much higher in the dry season and lowers in the rainy season, because other water sources like rainwater become more important.

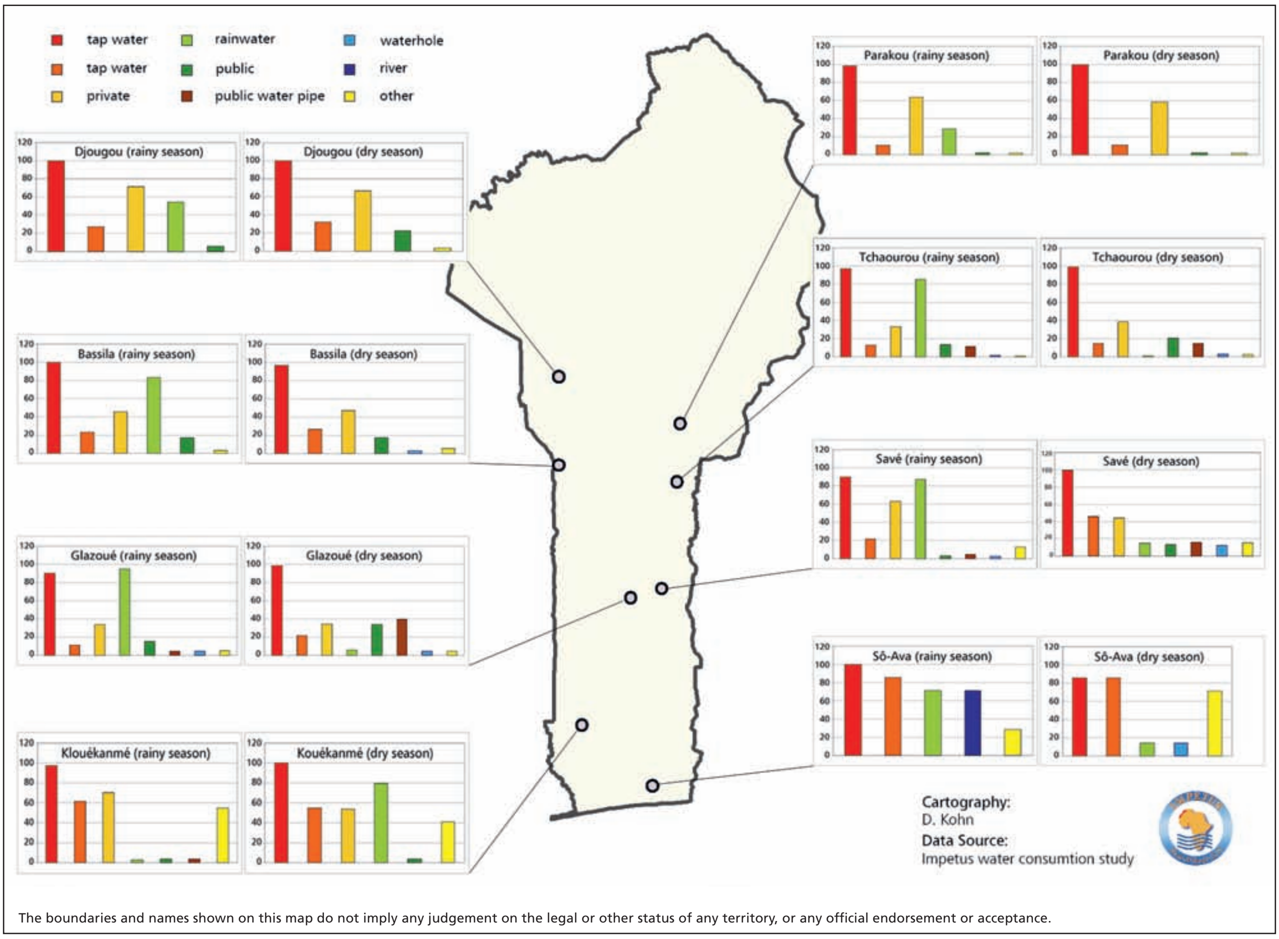

Fig. 2*: Frequency of using different water sources in the investigated cities.*

Comparing all water sources (by absolute values, Fig. 2), tap water was the most important source in the investigation areas, followed by rainwater and wells. As waterholes are frequently used in the rural areas, the opposite was observed for urban areas. In towns with extreme water shortages in the dry season (e.g. Glazoué), the population has constructed cisterns to collect rainwater to bridge the time when there is not enough tap water or water from wells.

In Parakou, for example, 48.3 % of all interviewed persons mentioned the use of tap water in the rainy season, compared to 57.5 % in the dry season.

Everywhere, sold tap water plays an important role. From the rainy to the dry season the importance of water sales increases. The highest value at the town level was found in Sô-Awa, a small town near Cotonou. Participatory observations confirm these results and support that the classification according to the created water index would also confirm the underlying theory.

For a detailed analysis, see Hadjer et al. (2005).

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Men preparing a yams field. The plants will be stuck into the earth heaps.


Geology,
Geomorphology and Soils

27

Soil Map of Benin

Simone Giertz and Claudia Hiepe

A large variety of soils can be found in Benin. Fersialitic soils with high gravel contents are dominant on the crystalline basement, while ferralitic and hydromorphic soils prevail in the sedimentary basins in the south of Benin. In general, small scale variability of the soils is very high, and many soil types are associated with other soil types.

Methodology

In the late 1980s, French scientists from ORSTOM (now called IRD) created soil maps for Benin based on a geological map and additional field surveys. They completed 10 soil map sheets covering the entire country (Volkoff et al., 1976-78).

In the context of IMPETUS, we scanned, georeferenced, digitized and merged these maps into one digital soil map. For presentation purposes, the map shown on the next page was simplified by neglecting the differentiation of soil types according to the underlying geology. The soil types are classified according to the French classification systems (CPCS). Translating the French soil classification into WRB or FAO soil types is difficult due to different classification criteria for fersialitic and ferallitic soils.

Soil distribution in Benin

A close look at the soil map for Benin reveals that ferallitic and hydromorphic soils dominate in the southern part. The crystalline basement in Central Benin is mainly characterized by Acrisols and Lixisols (*sols ferrugineux lessivés*). In the Atacora Mountains in north-west Benin, shallow soils (Lithosols, *sols peu evolués lithiques*) are widespread.

Limitations

The soil map has several limitations. First, the polygons of the soil map represent only the dominant soil type in an area and cannot reflect the small scale variability of soils along the hillslopes (↗33). Therefore, the soil map cannot be used for small scale evaluations of soil suitability for agricultural production. Furthermore, the soil map does not take into account the hydromorphic soils that can be found in inland valleys along upstream rivers. Understanding the distribution of these soils would be useful for hydrological modelling and predicting the agricultural potential of inland valleys in Benin.

Nevertheless, the soil map provides useful information about the large scale distribution of soils in Benin.

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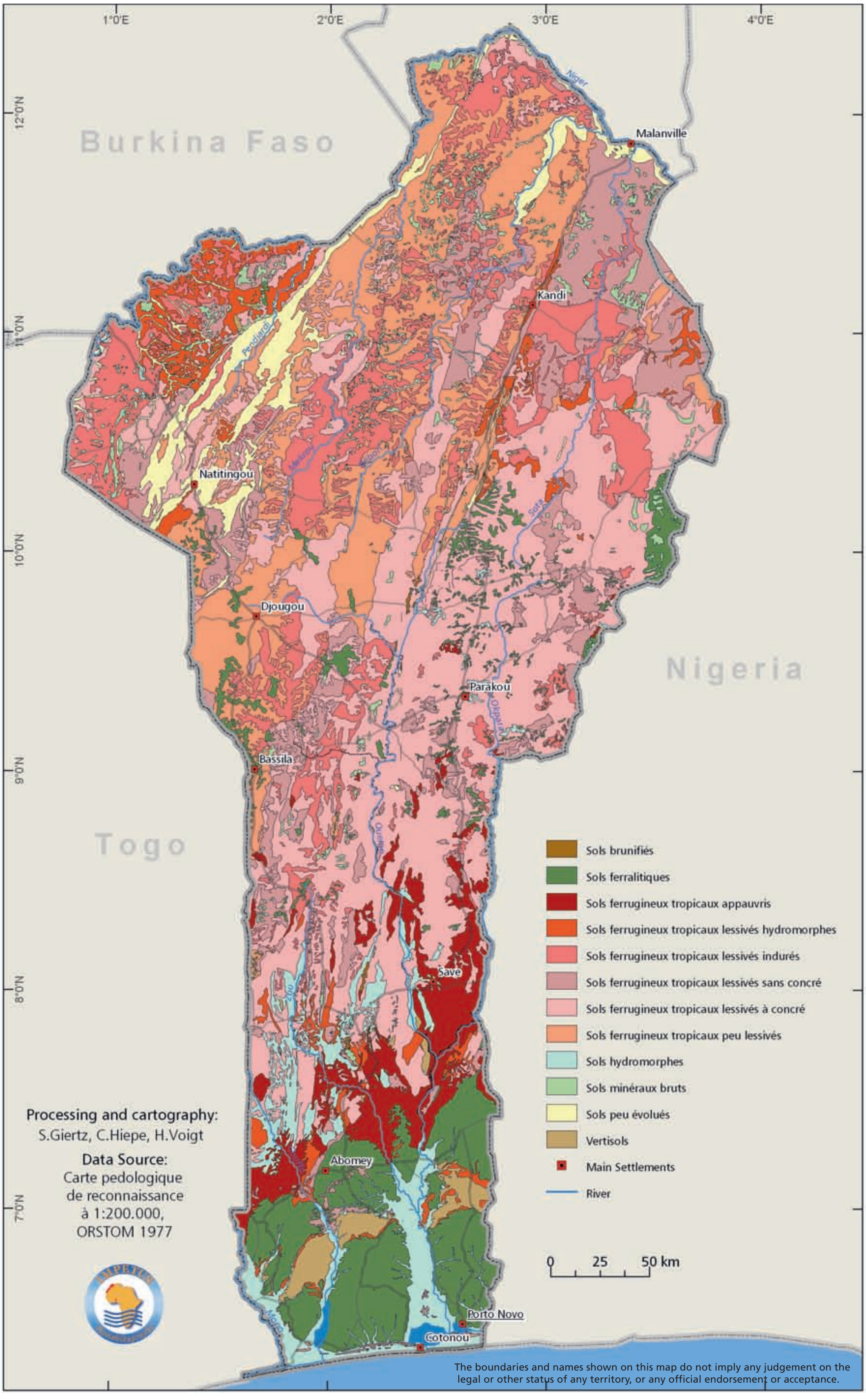

***Fig. 1**: Distribution of soil types in Benin.*

28

Geomorphology of Benin

Simone Giertz and Sarah Schönbrodt

The geomorphology of Benin is closely linked to its geologic structure. The main geologic units of Benin are the re-metamorphised Precambrian basement complex of the Dahomeyen Series and three sedimentary basins, located in North (Kandi basin and Precambrian Volta basin) and South Benin (Coastal basin).

The relief in Benin is flat, varying from only a few meters at the coastal plain to the Atacora mountain range in the north-west with its highest elevation at Mt. Sokbaro (658 m). Benin is subdivided into three major geomorphologic units on the flat sedimentary plateaus and seven on the crystalline basement (see Fig. 2).

The Coastal and Kandi Basins are characterized by even landscapes with gently hilly plateaus. Their development is due to varying resistance to weathering and erosion of various sediments and deposits (Faure and Volkoff, 1998). In addition, in the fertile "terre de barre," the southern Coastal Basin further comprises lagoons and estuaries. Erosion and flood plains of the Pendjari characterize the Volta Basin. Framed by these sedimentary basins and slightly connected to them, the basement complex is located in central Benin. It is divided by the Kandi fault into a Western and an Eastern Bloc whose parent rocks differ in their degree of metamorphism. Depending on the parent rocks, the surfaces are slightly undulated, like the granitic-gneissic peneplain of Kouandé-Péhonco and Parakou Plateau, or strongly fractured, like the granulitic peneplain of Pira, which forms the lower base of the plateau of Djougou into the Basin of Ouémé. The most rejuvenated landscape of the basement is the peneplain of Nikki, due to drainage of adjacent Nigerian basins. According to Rohdenburg (1969), slope pedimentation and climate change are the principal evolutionary factors of the peneplains, with their characteristic scattered, isolated or grouped inselbergs (Fig. 1).

Further typical morphological forms in Benin are the flat and linear seasonally waterlogged depressions without a marked stream channel in the headwater zones. These so-called "inland valleys" are the most considerable valley shapes in Sub-Saharan Africa (total area of 1.3 million km²). They mainly occur on pediplains with an intensive chemical deep weathering over a clayey saprolitic zone. Inland valleys exhibit a concave cross profile with gently tilted slopes, a flat valley bottom and a gently tilted longitudinal profile (Fig. 2). Due to their high water availability, they are often used for rice cultivation (↗45).

***Fig. 1**: Group of Inselbergs near Savé*

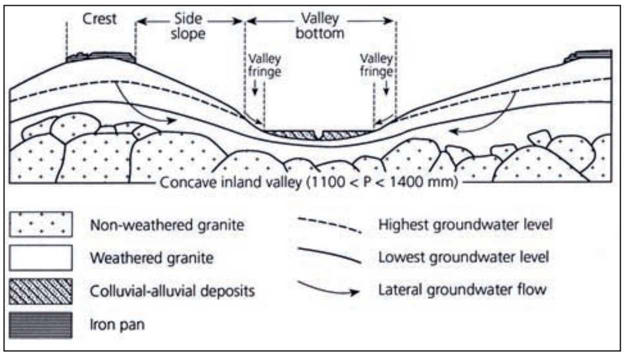

***Fig. 2**: Cross-section of a concave inland valley (according to Windmeijer and Andriesse, 1993).*

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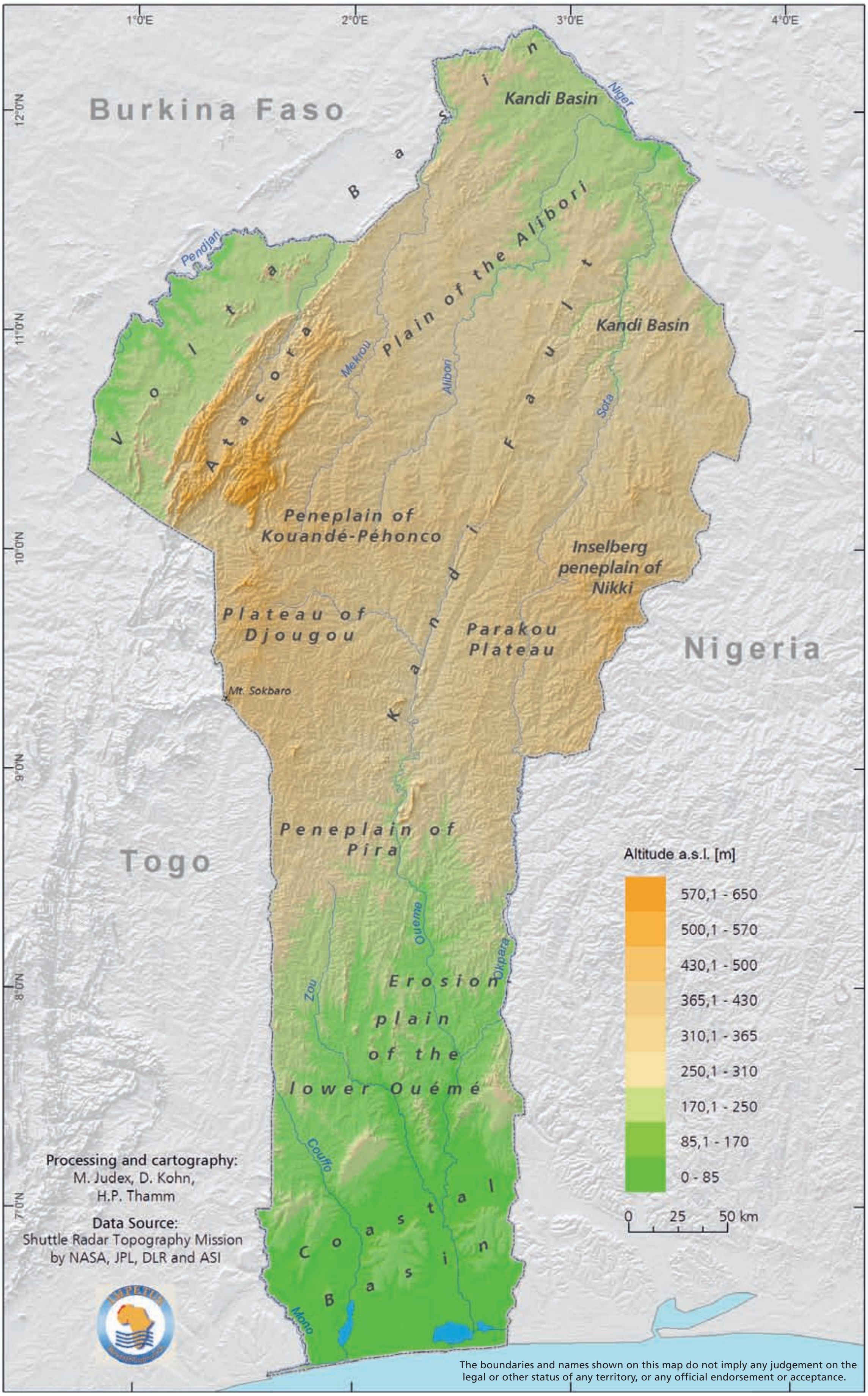

***Fig. 2**: Landscape units in Benin.*

29

Geology of the Ouémé Catchment

Tobias El-Fahem and Antoine Kocher

Benin lies extensively on Precambrian crystalline basement, known as the Dahomeyides or the Benino-Nigerian shield. It consists predominantly of granites, granitoid gneisses, and gneisses. The remaining 20% of Benin are occupied by sedimentary basins.

General geology

Benin is situated at the eastern edge of the West African craton, which consists of igneous rocks such as granite. Folding of the Precambrian formations is strong. The superposition of different tectonic phases is shown by the existence of intense fracturing and major faults of many kilometres length, as well as by various grades of rock metamorphism. The thickness of the fractured zone is variable. Ultramylonite bands accompany many of the faults.

Three major tectonic events characterize the area of the Dahomeyides and partially all of the West African craton. The first was the Pan African orogenesis (500–670 Ma), where the West African craton collided with the East Saharan craton and several micro-continents aggregated. In the Triassic-Liassic (180–245 Ma), West Africa experienced a generally tensional regime accompanied by magmatic events in relation with the opening of the Central Atlantic. In the lower Cretaceous (120 Ma), the western Coastal basin opened, leading to a sedimentary series composed of clay, sands, gravel, ferruginous sandstone, and fluvial deposits. At the beginning of the Cenozoic (65 Ma), a warm and humid climate dominated in West Africa, causing intense alteration processes.

The crystalline bedrock is covered by its weathering product, the regolith, which is quite heterogeneous in Benin. The weathering of the crystalline formations in West Africa is the result of physico-chemical disaggregation of the magmatic and metamorphic rocks due to two climatic factors: water and temperature. The ferralitic weathering of the bedrock occurred in several steps. First, the outcropping surface of the original bedrock is transformed. While the fresh bedrock was fractured, the saprock (transitional part between bedrock and regolith) was additionally fissured. Propagation of weathering along the fissures led to isolated boulders and rocks in a matrix of regolith.

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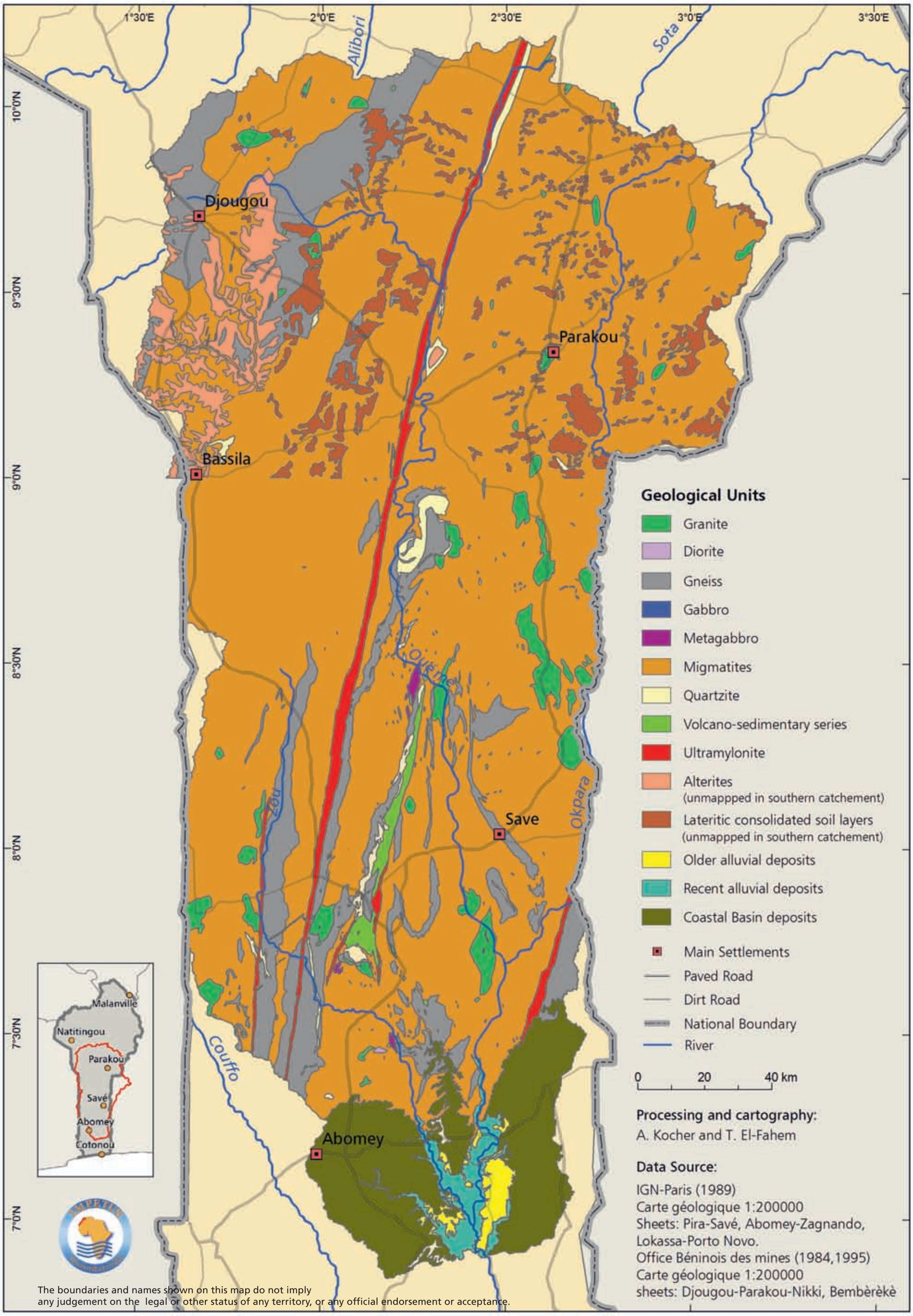

Fig. 1: *Map of the geology in the Ouémé catchment.*

30

Soil Map of the Upper Ouémé Catchment

Claudia Hiepe and Simone Giertz

Knowing the spatial distribution of soils and their physical and chemical properties is a prerequisite for applying hydrological models and spatio-temporally analysing hydrological and erosive processes at the catchment scale.

Methodology

The soil map of the Upper Ouémé catchment 1:200,000 is extracted from the soil map for Benin from the late 80s by French scientists from ORSTOM (now called IRD), based on the geological map and field surveys. For modelling purposes, we performed a field survey to link the soil types with current physical and chemical soil properties.

Soil distribution

The soil map shows that in the Upper Ouémé catchment, the group *sols ferrugineux tropicaux lessivés* dominates the region, and that corresponding subgroups are closely associated with it. Ferricretes (*sols ferrugineux tropicaux lessivés indurés*) are only widespread in the western part of the catchment, on the Djougou plateau and on residual hills. The occurrence of *sols mineraux bruts* and *sols peu evolués* reflects the distribution of Inselbergs. Soils with low clay eluviation, i. e. showing a homogenous clay distribution with depth, can be found only in the west of the catchment where gneissic rocks dominate. Soils without nodules are limited to migmatitic areas. Almost all soils have loamy sandy topsoils.

Limitations

The polygons of the soil map represent only the dominant soil types and do not reflect the small scale variability of soils along hillslopes. As a result, the soil map cannot be used for small scale evaluation of soil suitability for agricultural production. Furthermore, the soil map does not take into account the hydromorphic soils in inland valleys along upstream rivers, which would be relevant for hydrological modelling and predicting the agricultural potentials of inland valleys in Benin.

Another challenge is translating the French soil types into the modern WRB classification system, which is more suitable if one is interested in soil properties rather than pedogenesis. Problems arise, for example, for the soil group *sols ferallitiques*, which can be classified as Acrisols, Lixisols or Ferralsols depending on the vertical clay distribution and base saturation.

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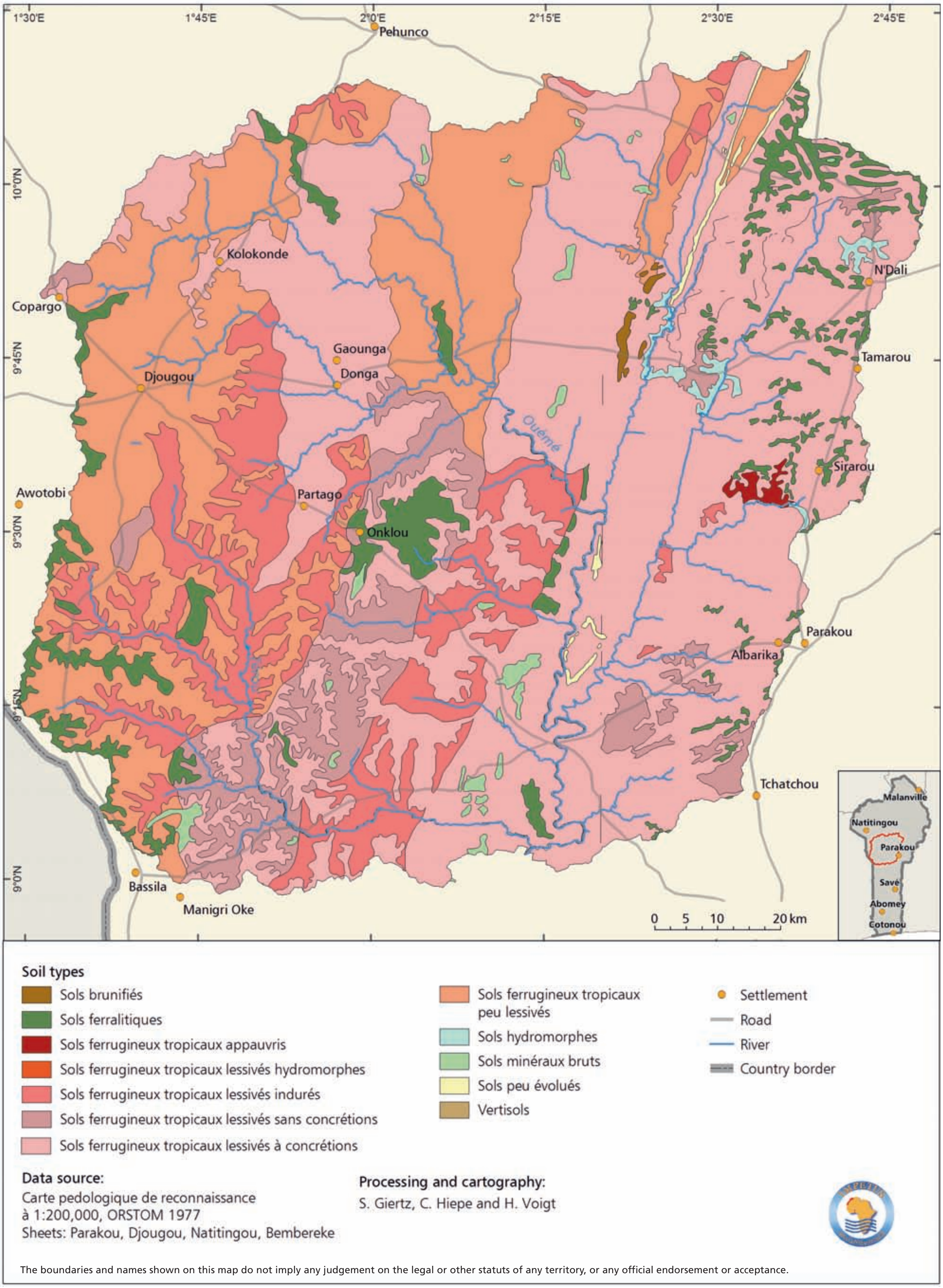

***Fig. 1:** Soilmap of the upper Ouémé*

31

Erosion Modelling in the Upper Ouémé Catchment – Status quo

Claudia Hiepe

Soil erosion leads to deterioration of topsoil and significantly reduces agricultural productivity. Erosion models are valuable tools to study the extent and causes of soil erosion at the regional scale and to extrapolate into the future, and thereby identify priority intervention areas for soil conservation measures.

Motivation

Although the Upper Ouémé catchment is characterized by gently undulating relief, soil erosion is a considerable problem in some parts of the catchment. Soil erosion as part of general soil degradation (losses of nutrients and organic matter, compaction) will probably be aggravated in the future due to rapid expansion of agricultural area with shorter or without fallow periods, a lack of soil conservation activities and increased rainfall variability due to climate change.

Methodology

The SWAT model (Soil Water Assessment Tool) was applied to analyze hydrological and erosive processes in the catchment. This is a semi-distributed model, i.e. it takes into account the spatial variability of land use and soils (see Fig. 1). Prior to calculating future land use change and climate change scenarios, the model was tested for the period 1998–2005. It was calibrated at the outlets of subcatchments Terou-Igbomakoro and Donga-Pont and validated at several other outlets. Hydrology was calibrated for 1998–2001. Then, the sediment budget was calibrated using suspended sediment concentrations from continuous turbidity measurements in 2004/05. On this basis, current hotspots of soil erosion were identified.

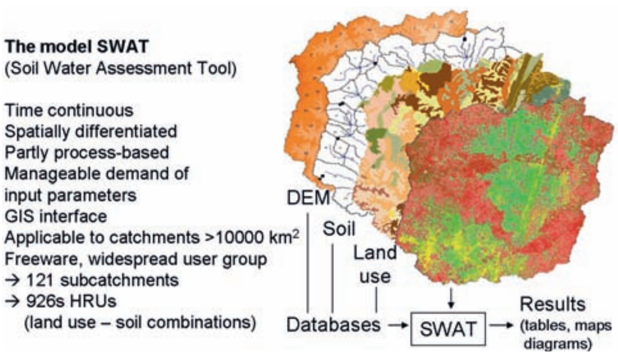

Fig. 1: The Soil Water Assessment Tool.

Model calibration and validation

It is crucial to represent hydrological processes well in order to adequately simulate sediment yield. The measured discharge and discharge components at river outlets Terou-Igbomakoro and Donga-Pont were reproduced well by the model for the calibration and validation period (see Fig. 2). Sediment calibration was also successful (see Fig. 3).

Thus, the model is applicable to the Upper Ouémé catchment and can be used for scenario analysis (↗32).

Results 1998–2005

The modeling results for the period 1998–2005 are summarized for the whole catchment and two subcatchments (see Tab. 1). In the Upper Ouémé catchment, the average sediment yield is 0.22 t/ha/yr.

However, in some subcatchments, sediment yields amount up to 2.25 t/ha/yr (see Fig. 4). The highest water and sediment yields were simulated for 1998/99 and 2003. The peaks of monthly water and sediment yields are in August and September, corresponding to the maximum in total rainfall and the large number of erosive rainfalls during this period.

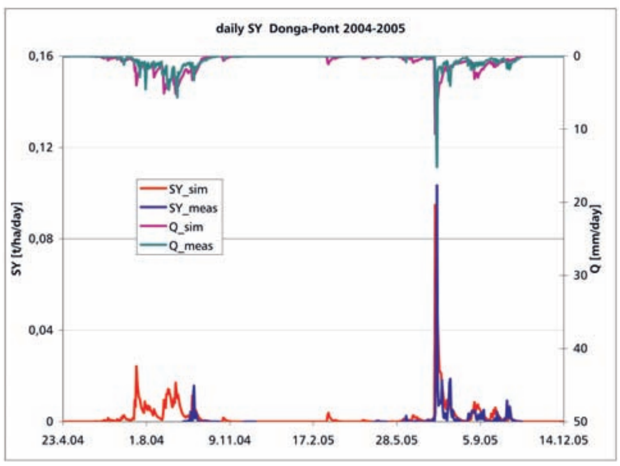

Fig. 3: Daily measured (SY_meas) and simulated (SY_sim) sediment yield in the calibration period.

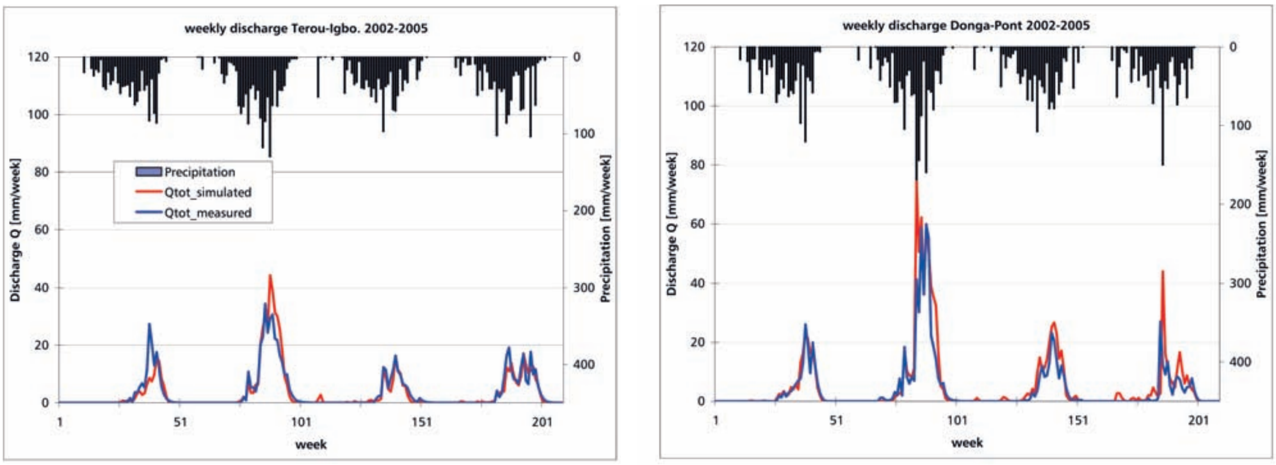

Fig. 2: *Model validation: Comparison of simulated and measured weekly discharge at Terou-Igbomakoro and Donga-Pont outlets; measures of performance (model efficiency (ME), coefficient of determination (R^2), index of agreement (IoA)).*

Taking the intensively used subcatchment Donga-Pont with almost 40 % cropland area as an example, 59 % of the water yield run off leads to an almost four times higher sediment yield than for the Terou-Igbomakoro catchment. Cropland is by far the main contributor to the sediment load (96.9 %), followed by brush and grass savannah (2.4 %).

In summary, current areas with high erosion rates are located around the cities Djougou and Parakou and along the main roads. The main driving factor is agricultural use. In the Djougou region, erosion is enhanced by higher rainfall amounts and intensities compared to the rest of the catchment. In large parts of the catchment, erosion rates are still low.

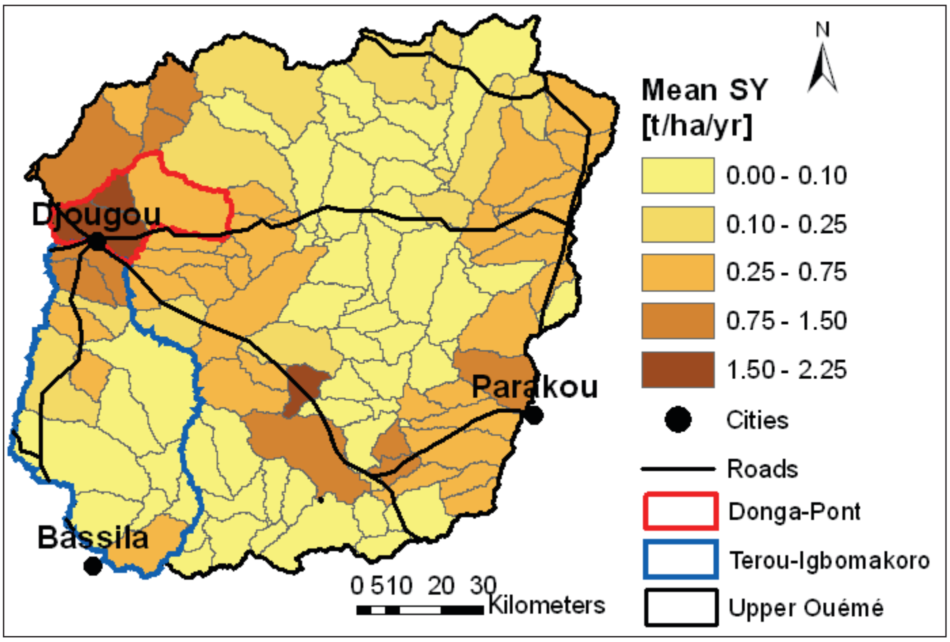

Fig. 4: *Mean sediment yield in the Upper Ouémé catchment (1998-2005).*

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Tab. 1: *Model results 1998-2005. WY: water yield, SY: sediment yield.*

	Field [%]	Savannah [%]	Forest [%]	Rainfall [mm/yr]	WY [mm/yr]	Qsurf [mm/yr]	SY [t/ha/yr]
Donga-Pont	39	61	0	1294	297	174	0,85
Terou-Igbomakoro	11	72	17	1157	213	96	0,14
Upper Ouémé	14	78	8	1184	219	107	0,22

32

Erosion Modelling in the Upper Ouémé Catchment – Scenario Analysis

Claudia Hiepe

Soil erosion by water deteriorates soil quality and can heavily affect crop productivity, especially in low input farming systems. Rapid expansion of agricultural areas and an increase in extreme rainfall events due to climate change will increase soil erosion by water in Central Benin in the future. On the other hand, mean annual rainfall may be reduced. Erosion models are valuable tools to study the effects of land use and climate change on erosive and hydrological processes at the regional scale.

Methodology

Successful application of the SWAT model (Soil Water Assessment Tool) to the Upper Ouémé catchment for 1998–2005 was a precondition for analysing future scenarios (↗31). Two climate scenarios and three land use scenarios were applied separately and in combination for the period 2001–2050 (see Fig. 1).

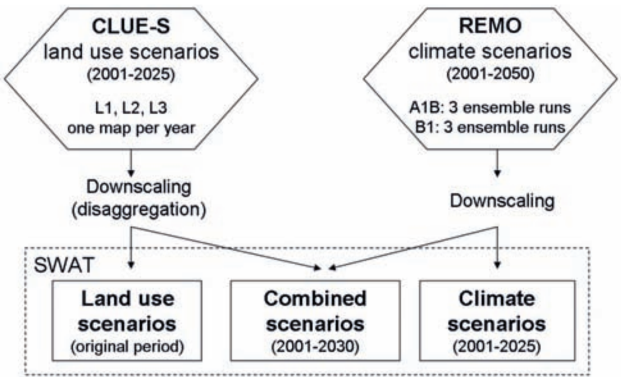

***Fig. 1:** Overview of scenario analysis.*

The land use maps for 2005, 2015 and 2025 (Lu05-Lu25) for the three land use scenarios L1, L2, L3 were derived from the CLUE-S model (↗40) and reflect an expansion of cropland area by 51–108 % by 2025 depending on specific scenario assumptions. The climate scenarios were derived from the regional climate model REMO (↗5). The grid-based REMO results based on the IPCC SRES scenarios A1B (globally-economy oriented) and B1 (globally-sustainability oriented) were statistically post-processed and attributed to individual climate stations. The scenarios results were compared to the results of the original model for the period 1998 – 2005.

Land use scenarios

All land use scenarios lead to significantly increased surface runoff and sediment yield, while changes in total water yield and all other components of the water balance are negligible (see Fig. 2).

By 2025, the sediment yield increases by 42 % to 95 % depending on the land use scenario. These trends are even more pronounced for the not yet intensively used subcatchment Terou-Igbomakoro. However, the erosion rates in this subcatchment have not yet reached the currently high erosion rates in the Donga-Pont subcatchment.

Climate scenarios

For a slight increase in potential evapotranspiration and a reduction in mean annual rainfall by 3 % (scenario B1) for the period 2001–2025, water yield decreases by 5 % and sediment yield by 12 %. For scenario A1B (4 % decrease in rainfall), the figures are -5 % and -14 % for water and sediment yield, respectively. For the period 2026–2050 and parts of the catchment (e.g., Donga-Pont), the reductions are even more drastic, reaching up to 35 % (Fig. 3).

Conclusions

Land use and climate change scenarios show opposite effects on water and sediment yield. For com-

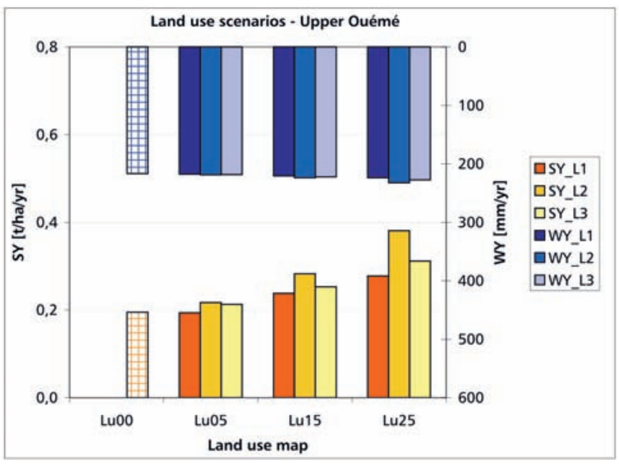

***Fig. 2:** Simulated water (WY) and sediment yield (SY) for land use scenarios L1-L3.*

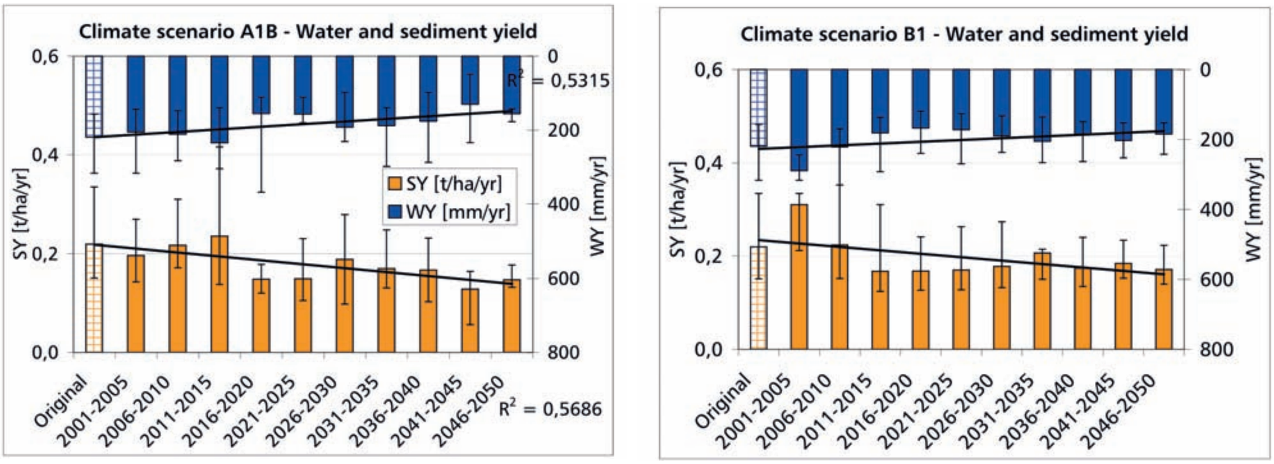

Fig. 3: Averaged simulated water (WY) and sediment yield (SY) for the climate scenarios; bars reflect variations between the three ensemble runs from climate model REMO.

bined scenarios, the average water yield decreases by 4 % to 12 % for the period 2001–2025 due to climate changes according to REMO. Sediment yield (increase or decrease) depends on the scenario and the location of the subcatchment. All combined scenarios cover a range of -4 % to +17 % for the average annual sediment yield for 2001–2025 in the Upper Ouémé catchment. However, in the Terou-Igbomakoro subcatchment, sediment yield increases by up to 25 %. The spatial pattern of soil erosion rates remains similar, with high erosion rates in the NW and E of the catchment (Fig. 4). New 'hotspots' of soil erosion arise in the south of the catchment. Soil conservation activities should be extended in these areas.

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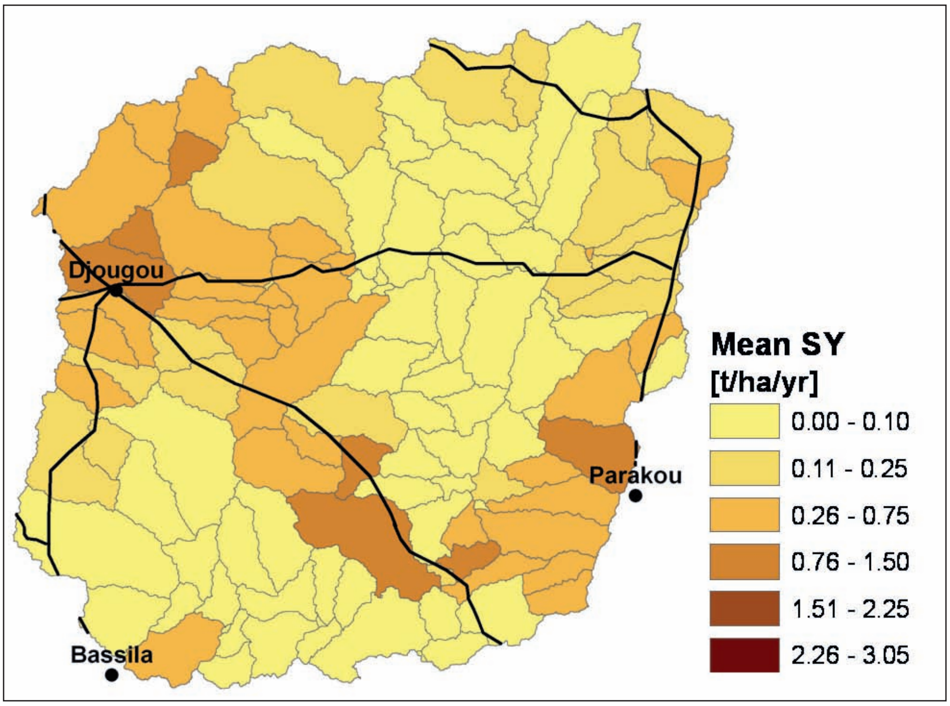

Fig. 4: Future hotspots of soil erosion – Results of combined scenarios.

33

Soil Distribution in the Aguima Catchment

Claudia Hiepe and Birte Junge

The small scale variability of soils in Central Benin is high. Detailed knowledge about the spatial distribution and the properties of soils is essential for understanding local hydrological processes.

Methodology

Soil distribution in the Aguima catchment was investigated by Junge (2004) in 2001/02 along 8 transects. In total, 522 auger drillings and 56 representative profiles up to 2 meters deep were studied. The profiles were classified according to various classification systems (CPCS, WRB, FAO), and a typical sequence of soil types along the hillslope was identified. In the new map (Fig. 2), soil types were determined with additional information from remote sensing data and the topographic map 1 : 50.000.

Soil distribution

The French soil map from ORSTOM shows that in the Aguima catchment the only dominant soil type is sols *ferrugineux tropicaux lessivés* with the subgroups *avec/sans concrétions* and *indurés*. This coarse soil map is insufficient for understanding the hydrological processes at the local scale (↗18). The new detailed soil map reflects the typical soil sequence (see Fig. 1) and includes minor distributed soils like Fluvisols, Lithosols and Gleysols. On some summits and on the lower slopes, we find soils with a plinthic horizon (Plinthosols, 15 % of the catchment). The upper and mid-slopes are dominated by Lixisols and Acrisols (60 %), which are deeper and more fertile than Plinthosols. In the inland valleys, Gleysols (12 %) occur, i. e. hydromorphic soils with a sandy texture and high permeability at the border, and richer in clay and nutrients towards the centre. In the fluvial plain, Fluvisols with high pH and base saturation predominate. Termites can modify the typical soil sequence by producing loamy topsoils with high base saturation. Relatively young and fertile red Acrisols exist around the Inselberg Mt. de Gaulle (4 %).

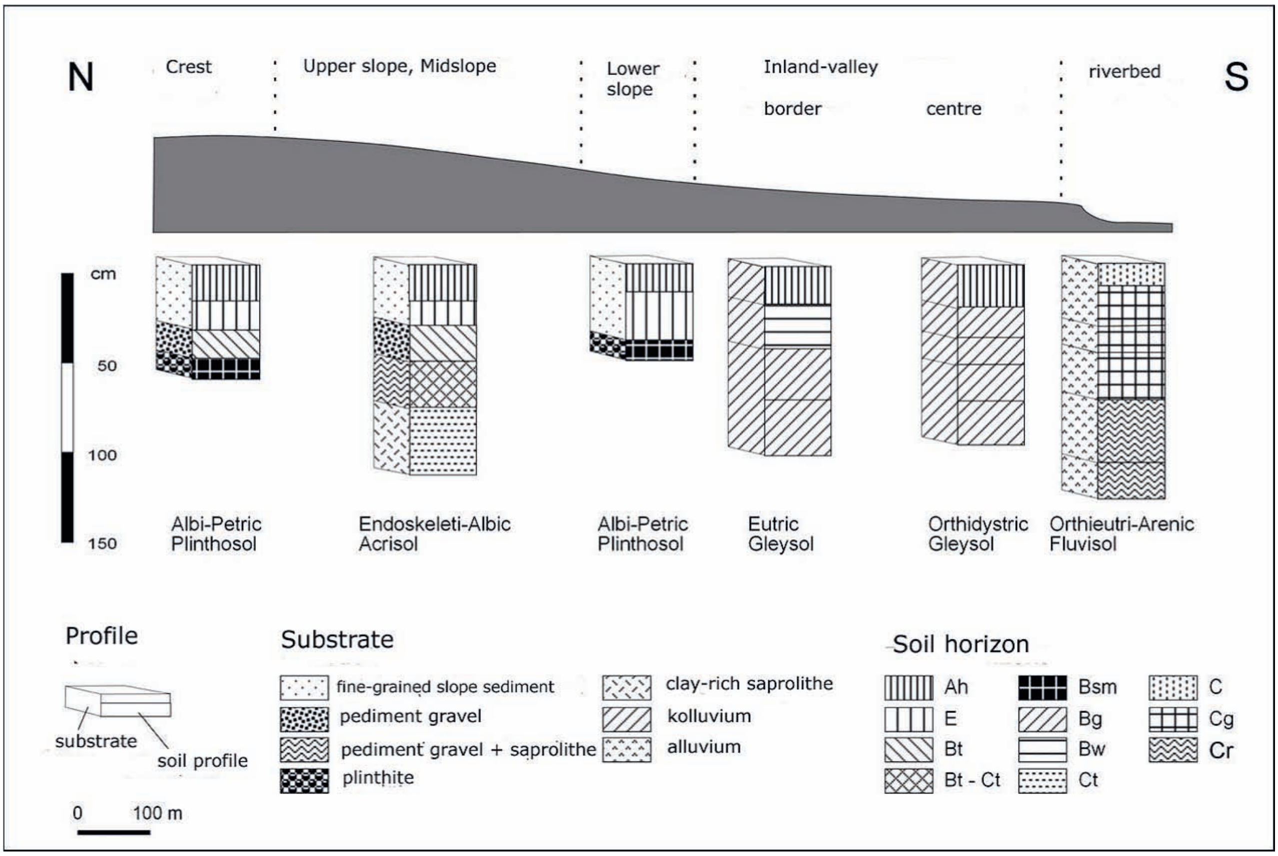

Fig. 1: Typical soil sequence – Aguima catchment

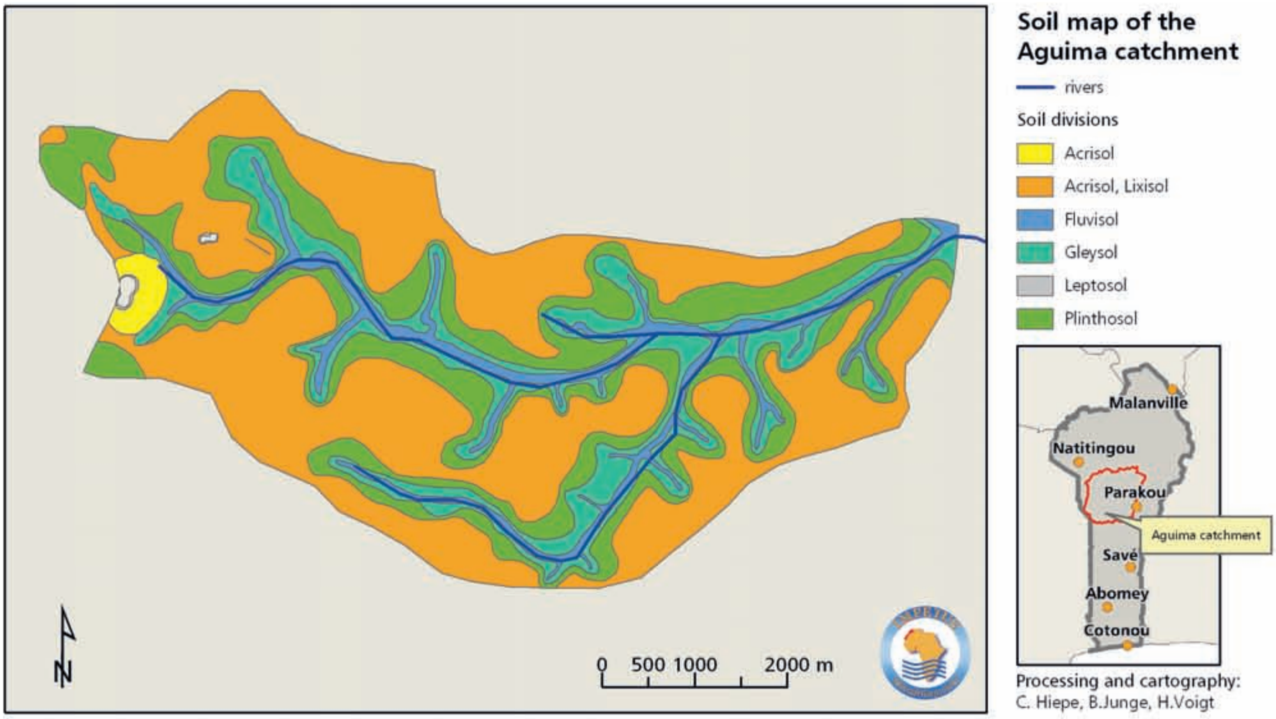

***Fig. 2**: Soil map of the Aguima catchment.*

Farmers' soil classification refers only to the first horizon and distinguishes *Ile odan* (sandy field soils), *Ile yibo* (sandy soils on savannah) and *Yangari* (degraded gravelly topsoils).

Soil fertility

Most soils are limited by the low available water capacity due to low rootable depths, sandy material and high gravel contents. Kaolinitic clays and low organic carbon content lead to low nutrient content. Only the soils around Inselbergs and termite mounds and the soils in the valley bottoms and inland depressions are more fertile. Most soils are moderately suitable for agricultural production.

References

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34 Soil Erosion in the Aguima Catchment

Claudia Hiepe and Birte Junge

Soil erosion by water is important because topsoil loss can significantly deteriorate physical and chemical soil properties. In Central Benin, where farmers cannot afford inorganic fertilizer, soil erosion can affect soil fertility and agricultural production considerably.

Methodology

In 2002, Junge (2004) installed erosion plots (10 x 1.60 m²) on fields with different crops (cotton, maize, yam) and tillage systems (rows, mounds), and under natural savannah in order to measure surface runoff and soil loss. Slope gradients ranged from 3.5 to 4.3 %. After each rainfall event, the amounts of water and eroded soil material collected in the tanks were weighed. Furthermore, sediment traps with collecting branches (2 x 0.2 m²), a collector box (0.5 m³) and erosion nails were installed (see Fig. 1), and changes in micro-relief and erosion forms were mapped. A tracer experiment identified the transport length of the eroded material.

Selected results

Surface runoff and soil loss on erosion plots differed significantly between crops and tillage systems (see Figs. 2 and 3). The highest amounts of soil loss were observed on plots with cotton planted in rows in the direction of the slope (runoff 229 mm / yr, soil loss 124 t / ha / yr, data not shown) and on plots with yam mounds (168 mm / yr runoff, 41 t / ha / yr). In contrast, surface runoff and soil loss were much lower on fields with crops planted parallel to the contour lines (e. g., cotton, runoff 106 mm / yr, soil loss 13 t / ha / yr), because the water flowing downhill was slowed. On savannah plots, runoff (50 mm / yr) and soil loss (4 t / ha / yr) were up to 20 times lower. The monthly values for soil erosion and surface runoff in the catchment reach a maximum in April, August, and September (Fig. 3). This pattern can be explained by the sparse vegetation cover and dry soil during the first rainfalls and the completely saturated soils in August and September (↗ 18).

In general, the higher soil erosion rates on fields can be explained as a consequence of the mechanical destruction of the soil structure and soil cover that shades the soil: biological activity (e. g., earthworm density) decreases and therefore reduces the macroporosity. The induced lower permeability of the soil surface causes higher surface runoff and soil erosion. Furthermore, the selective loss of finer soil particles leads to higher topsoil gravel content delivered

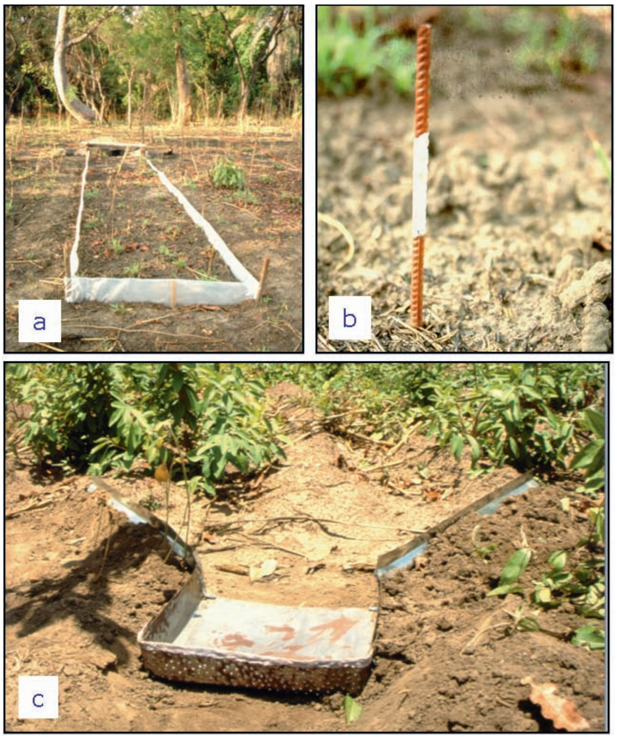

***Fig. 1**: Erosion plot (a), erosion nail (b) and sediment trap (c)*

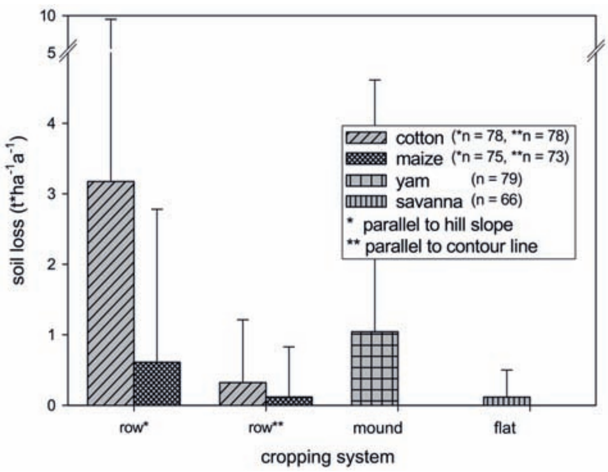

***Fig. 2**: Soil loss rates for 2002 for different cropping systems.*

by the B-horizon, lower organic carbon content and a deterioration of the soil structure in the first horizon.

With the unified soil loss equation (USLE), we cal-

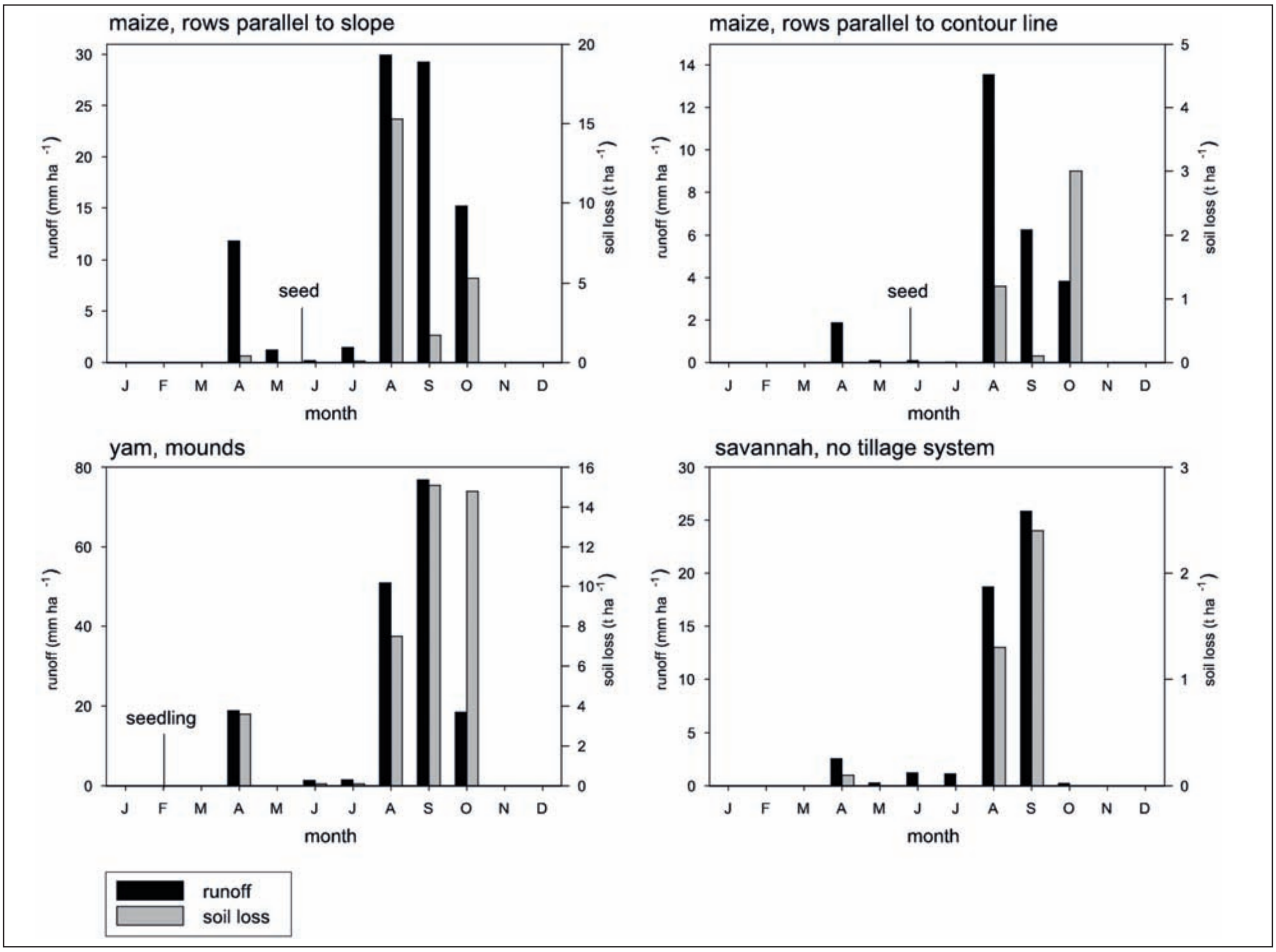

***Fig. 3**: Measured monthly runoff and erosion for various land uses.*

culated a long-term average of 20 – 27 t / ha / yr. The Aguima catchment is characterized by high rainfall erosivity (e. g., 33 erosive rains between 1997 – 2002, mostly in August and September). Except for the Gleysols in the inland valleys, the sandy topsoils on savannah land are not susceptible to erosion, resulting in medium erosion risk. Chemical analysis of soil properties showed that chemical degradation is not yet pronounced in the Aguima catchment but will probably increase due to rapid expansion of agricultural land and a shortage of fallow periods. Possible measures for soil conservation would be the reduction of human-induced fires, consistent cultivation perpendicular to the slope, and optimized crop rotation with legumes and organic fertilizer.

Limitations

Local erosion measurements were based only on one rainy season. In order to get robust results, long-term monitoring is required, taking into account the high rainfall variability in the tropics. For the same reason, the transferability of these results to other regions and scales is limited. Nevertheless, the results are valuable for comparing different land use and management systems and interpreting results from erosion modelling at the regional scale (↗31, 32).

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35

Hydrological Processes and Soil Distribution in the Ara Catchment

Gero Steup

The 13 km² Ara catchment is located in the north-west of the Upper Ouémé catchment near the city of Djougou. It has been used agriculturally for a long time, so hardly any natural vegetation remains, and most soils are severely degraded. An analysis of the hydrological processes in this region can provide information about the effects of a long period of cultivation on the hydrological cycle. Due to a fast growing population and migration in Benin, this may be representative for the future status of large parts of the upper Ouéme catchment.

In 2002, a water level gauge and three rain gauges were installed in the Ara catchment by the AMMA-Catch-Project. An automatic meteorological station in Djougou collects further climate data.

Total annual precipitation in the catchment is around 1200 mm. The hydrograph (Fig. 1) shows a discharge dynamic with high peak flow and high discharge volume. The runoff coefficient varies between 11 % in dry years to nearly 30 % in humid years like 2003 (Kamagaté, 2006). Similar hydrographs were observed in the upper Niaou catchment, which is also dominated by agricultural land use.

The high peak discharge is mainly caused by an increase in surface runoff on cropped land where infiltration rates are reduced. Figure 2 shows the results of in–situ infiltration measurements on different soil types and land uses. The data marked with the same colour are measured on the same plot within a range of only a few meters, on the same soil type, but with different land cover.

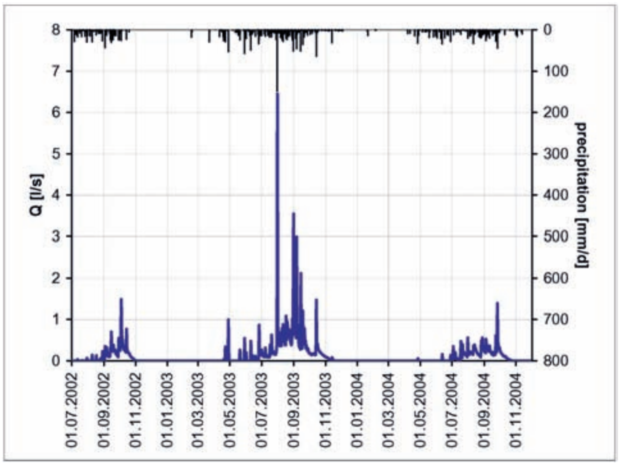

***Fig. 1**: Daily discharge of the Ara–catchment*

In order to understand the hydrological processes at the local scale and to acquire a database

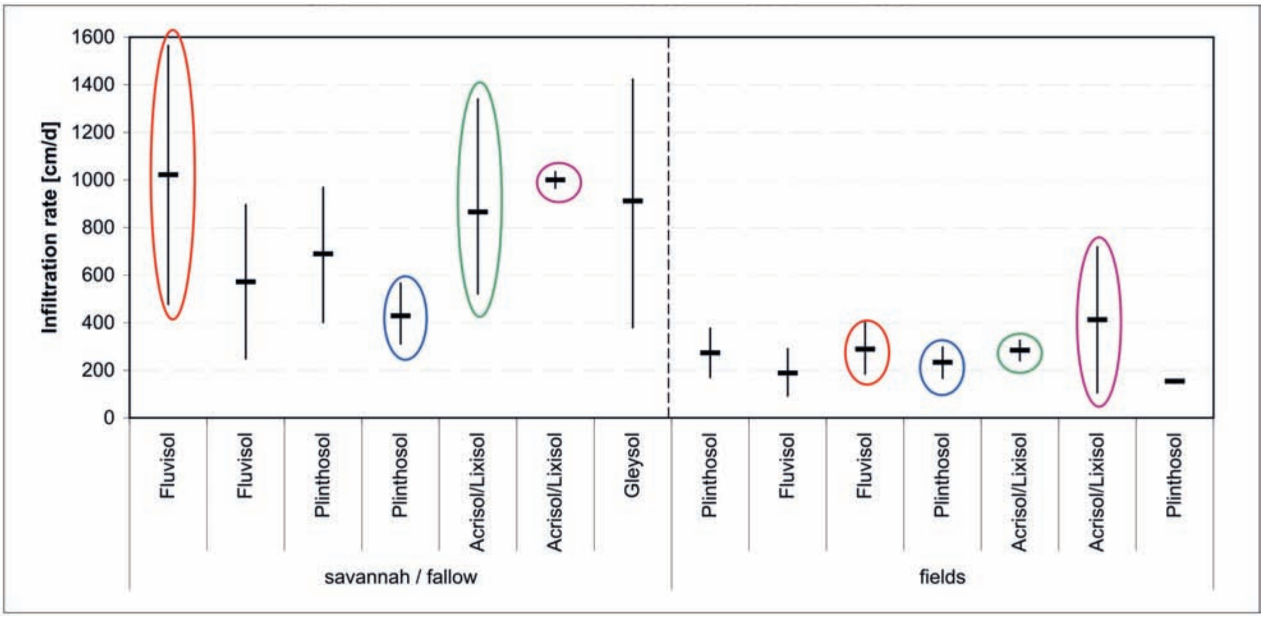

***Fig. 2**: Infiltration rates measured on different soil types and different land covers. Crossbar: arithmetic mean, tails: minimum and maximum, circles: same plot.*

for a physically based hydrological model, we investigated the soils of the catchment. 100 drillings and 30 soil-profiles up to 2 m depth were studied along three main transects. In addition, physical soil properties, such as texture, bulk density and vertically and laterally saturated conductivity, were measured in the laboratory.

The soils were classified according to the World Reference Base (WRB) classification. Figure 3 shows the resulting soil map for the catchment. In contrast to the Aguima catchment, the dominant soil type is Plinthosol, representing 46 % of the catchment. These soils are shallow and highly degraded with a plinthic horizon and high gravel content in the topsoil due to topsoil loss caused by surface runoff and soil erosion. Acrisols / Lixisols with a plinthic horizon form another 15 %, and deeper Acrisols / Lixisols 21 % of the soils. In the fluvial plain and inland valley, sandy Gleysols and Fluvisols can be found.

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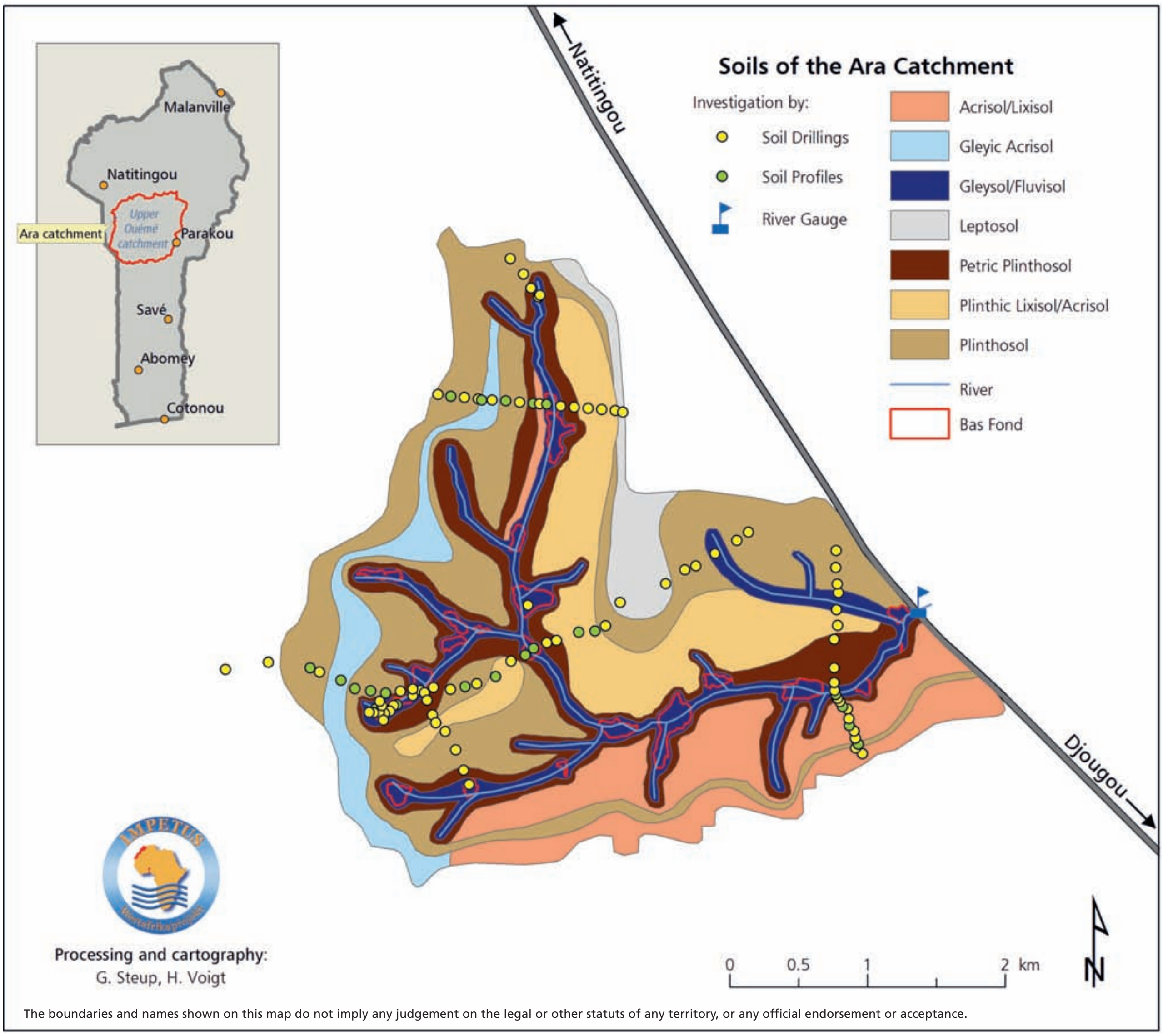


Fig. 3: Soil map of the Ara-catchment

Peri-urban gardening near Cotonou.

Land Cover and Land Use

36

Land Use in the Ouémé Catchment

Hans-Peter Thamm and Michael Judex

Vegetation cover is a result of a particular ecosystem and its modification by human activity. In the Ouémé catchment, land use is largely characterized by small-scale agriculture. In the northern part of the catchment, intensive agriculture can be found around the old settlements. A forest belt is located in the middle of the catchment. It has come under increasing pressure by agricultural expansion. The south of the catchment is characterized by large plantations and intensive agricultural land use.

Introduction

The catchment of the Ouémé River, the biggest river in Benin, reaches from 10° 09′ 33″ N to 6° 20′ 14″ N and has an area of about 51,000 km². Different vegetation zones can be found within the catchment. The northern portion of the catchment belongs to the Southern Sudan Zone, with vegetation that is characterized by woody savannas with varying grassy understory. In the southern part, the vegetation belongs to the Guinea-Sudan transition zone (White, 1983).

The natural vegetation, which is a result of the ecological conditions, has been modified by human activity. In different parts of the catchment the pattern of land use and land cover are very different, depending on the local density of the population.

Detailed description of the land cover and land use

The land use map (Fig.1) was created on the base of the MODIS / Terra Land Cover Type L3 in 1 km x 1 km resolution (source: http://edcdaac.usgs.gov/modis/mod12q1v4.asp). The classes were condensed and adapted and some improvements made on the base of LANDSAT images. It is not possible to distinguish different field crops due to the insufficient spatial and spectral resolution of the MODIS data, the generally small field sizes, the very heterogeneous land use pattern, and the frequent cloud cover in the rainy season.

In the northern part of the catchment, there are old settlement areas with high population density, e.g., around Djougou and Parakou. Most of the land is agriculturally used in small scale farming. Almost no forests remain as farmers struggle with an increasing shortage of cropland. Residues of dense forests are found around some villages, which are sacred places (called forêt sacré) that served as protection against slave hunters in former times (e.g., around the village Sérou).

Between Djougou and Parakou, there are vast protected state-owned forest areas (*forêt classée*) such as the *Forêt de Ouémé Superieur* and the *Forêt de Wari-Maro*. Along the Djougou-Ouberou-Parakou road, agricultural areas are expanding, and, in some areas, even the *forêt classées* are not respected and are converted into farmland.

South of the Bassila-Wari-Maro line, a zone with numerous forests and very low population density can be found. The few roads and paths are the routes for agricultural expansion along which new settlements are visible. Agricultural activities are mostly subsistence based but also partly oriented towards production for regional markets.

The middle of the catchment between 8° and 9° north latitude is the zone with the highest population growth in rural Benin. This has resulted in high deforestation rates, and, therefore, only few larger patches of forests remain. Characteristic land use patterns for that zone are a mixture of fields, fallows, and patches of forest. Large teak plantations can be found around Bohicon.

At the border with the erosion plain of the Ouémé, dense forests remain that benefit from favourable groundwater availability (e.g., *Forêt de Locoli, Forêt de Lama*). Even tree species of the humid tropics can still be found there.

Further to the South, large plantations of oil palms can be found. They are managed by large companies and produce oil for export.

The areas between the plantations are intensively used by small-scale agriculture. In the very South, two crop yields per year are possible due to the bimodal monsoon seasons. The few relicts of natural forests, mostly close to villages in this area, are generally “sacred forests” that have not been converted to agricultural land. In the south, starting around Bohicon, the settlement density increases due to high population density.

References

White, F. (1983): The vegetation of Africa. UNESCO, Paris.
NASA (2008): http://modis-land.gsfc.nasa.gov/landcover.htm

Intensive agriculture around Djougou

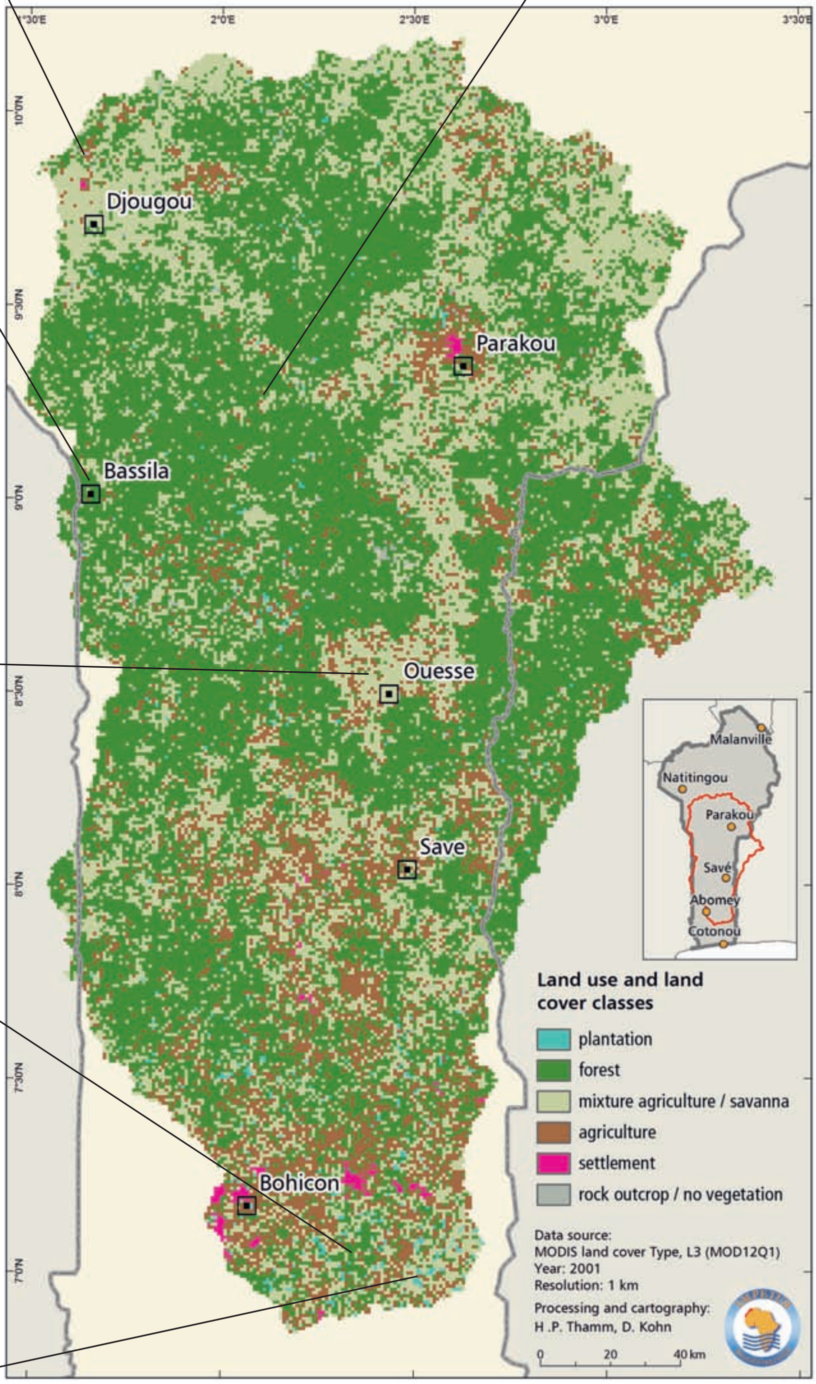
Mixture of savanna and agriculture around Wari Maro

New fields in the new settlement zone near Bassila

Intensive agriculture near Quesse

Very dense forest in the south of the catchment of the Ouémé

Palm plantations with factory in the south of the Ouémé catchment



The boundaries and names shown on this map do not imply any judgement on the legal or other statuts of any territory, or any official endorsement or acceptance.

Fig. 1: *Land cover and land use map of the Ouémé catchment with some example pictures.*

37

Satellite Imagery of the Upper Ouémé

Michael Judex, Hans-Peter Thamm and Gunter Menz

Special cameras on board satellites can produce images of large regions of the earth surface. These map the earth in different wavelengths, visible and near infrared, whereby various aspects of the earth surface are apparent. The IMPETUS-Project uses satellite images to derive comprehensive information about land use and land cover and to detect changes over time.

Satellite image techniques

Observation of the earth surface by satellite images has had increasing success since the early 1970s. Areas of application are important to many scientific disciplines: observing land use, land cover, geology and settlement, deriving biophysical data like biomass or leaf area index, or as input for weather forecasts.

Images are taken by sensor systems recording electromagnetic waves in different wavelengths (e.g., visible light, near infrared) that are reflected by the earth surface. Different surfaces have different reflections and are therefore distinguishable by image interpretation techniques (Fig. 1). Image acquisition is like photography, except that additional images are taken in spectral wavelengths (e.g., infrared and thermal) that are not visible to human beings.

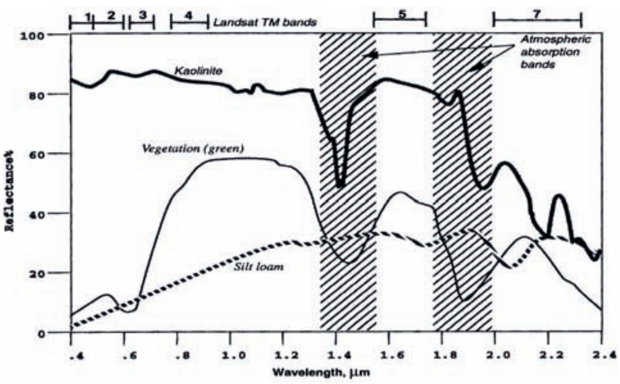


***Fig. 1:** Spectral reflectances of typical land cover units and recorded wavelength by LANDSAT satellite. (Source: ERDAS IMAGINE, 1995).*

Land cover in the satellite image

The satellite image presented in Fig. 2 was taken by LANDSAT 7, one of the most used satellites. It has a spatial resolution of 30 m x 30 m and covers an area of 180 km x 180 km in one image. The image is shown in real colour to facilitate visual interpretation. The acquisition time of the image was the 26th of October, at the end of the rainy season, which gives very usable data because nearly no clouds hamper the view and bushfires have not yet begun.

At first glance one can identify the huge forest and savannas in dark green and cultivated areas in light colours. The "triangle" in the centre is the *Forêt classée de l'Ouémé Supérieure* and at the bottom of the image a corner of the *Forêt classée de Wari-Maro* is visible. Generally, the darker the green, the denser the vegetation, i.e. dense forests are nearly black and light green areas are dominated by herbaceous vegetation. The bright spots in the middles of savannas are inselbergs, mountains of granite that overtop the surrounding landscape by several hundred meters.

The geological structure of the "Kandi fault", stretching from NNW to SSE (↗28), is clearly visible in the satellite image, as the vegetation pattern changes. Due to the shallow soils and quartzite stones, dry forests (*forêt claire*) develop on this structure, visible as a long lineation in the right centre of the image. The forests are not disturbed much by human activities because the soils are not deep enough for agriculture.

The red-violet areas, especially found in the northern part of the image, are areas with dried grass and some bushes. This vegetation occurs mostly on laterite crests with very poor soils or on rock outcrops.

Cultivated areas are also indicated by light colours, but in most cases are located around settlements and typically appear as mosaics of fields and fallow vegetation. Settlements come out as very bright white spots, recognizable by roads leading towards them. In the north-east and south-west, small clouds are visible as blue-grey fog.

The satellite image is the basis for the land use and land cover maps, created by image classification techniques (↗38).

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ERDAS IMAGINE (1995): Field Guide. Atlanta, Georgia.

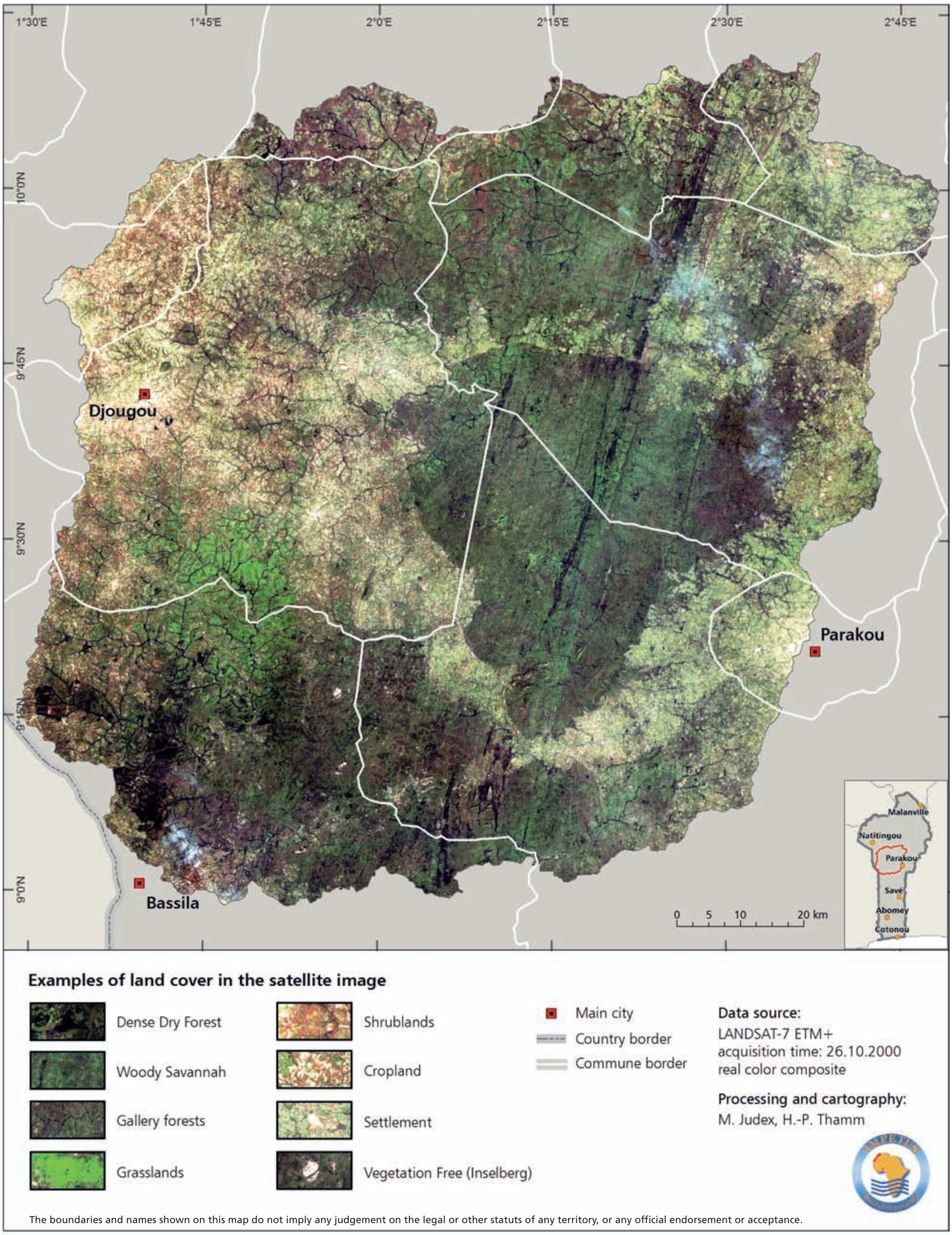

Fig. 2: Satellite image of the Upper Ouémé catchment.

Land Use and Land Cover in Central Benin

Michael Judex, Hans-Peter Thamm and Gunter Menz

Land cover and land use influence many aspects of the hydrological cycle, including surface discharge and infiltration. As a result, pertinent information about land use and land cover is important for a sound understanding of the ecosystem. We describe the derivation of land cover and land use information from satellite images for central Benin.

Deriving land use and land cover information from satellite images

Detailed land use and land cover maps can be derived from satellite images, as they provide detailed information even for areas that are not easy accessible. To assess land cover and land use in central Benin, we used images from the LANDSAT satellite from 2000 and 2001. These images have seven spectral bands and a ground resolution of 30 m x 30 m.

Based on a comprehensive ground truth database with several hundred training areas taken with GPS, we classified the satellite data using the modified maximum likelihood method. To determine classes, we applied a knowledge-based approach. Twelve classes were used to characterise land use and land cover in the study area, identifying different forest and savannah types as well as cultivated and settlement areas. To distinguish between dense forests and gallery forests and to improve the accuracy of the classification of inselbergs, a digital elevation model was used (Judex et al., 2006). With independent test areas, the total accuracy of the classification was estimated at 80.3 %.

Land use and land cover in the upper Ouémé catchment

Most of the forests in this catchment are located in its south-western part. These forests, together with dense savannas (*Savane boisée*), form quasi-natural areas or long-term fallows. However, the highest proportion of largely undisturbed areas is located in the protected zones of the *"forêts classées"*.

Land use in the upper Ouémé area is characterised by small-scale agricultural production systems with variable fallow cycles. Due to higher population densities, the areas around Djougou and Parakou are used intensively with very few remaining forests. Data on the distribution of land cover / land use classes are presented in Fig. 1.

Table 1 lists the shares of aggregated land cover categories for the main municipalities (*Communes*) in central Benin. The Commune Djougou has the highest proportion of agricultural land use (cropped areas only) with nearly 22 % of the total surface, while more than 50 % are occupied by savannah vegetation. As fallow cannot be distinguished from savannah vegetation, we assume that this land cover type refers to rotational fallow areas. Results indicate that almost the entire area is under (agricultural) use. The situation in the Commune Bassila is very different. Less than 5 % of the area is currently under use, while over 70 % of the area is (still) forest. Due to the extensive areas of available land, this Commune is an important target for 'rural-rural' migration leading to very rapid changes in land use and land cover (↗51).

Tab. 1*: Surface percentage of important land cover categories for four* Communes.

Commune	Forest	Savannah	Agriculture
Djougou	20.1 %	50.9 %	21.8 %
Bassila	72.0 %	23.0 %	4.8 %
N'Dali	56.2 %	34.3 %	9.3 %
Tchaourou	62.2 %	26.0 %	10.4 %

Forest = *forêt dense, forêt claire, savane boisée*;
Savannah = *savane arborée / arbustive, savane saxicole*

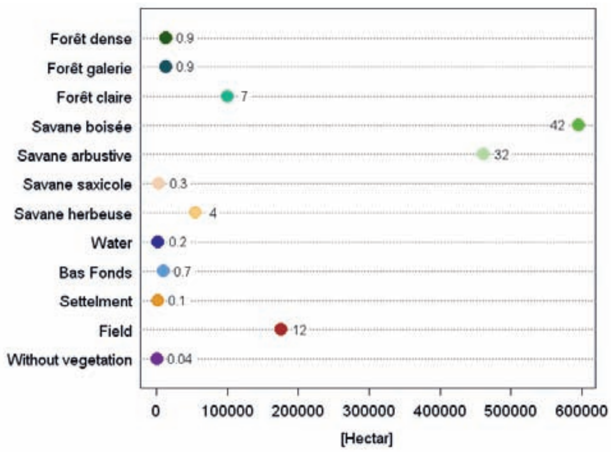

Fig. 1: *Areas of land use classes in upper Ouémé catchment. Number on the graph indicates fraction of total area.*

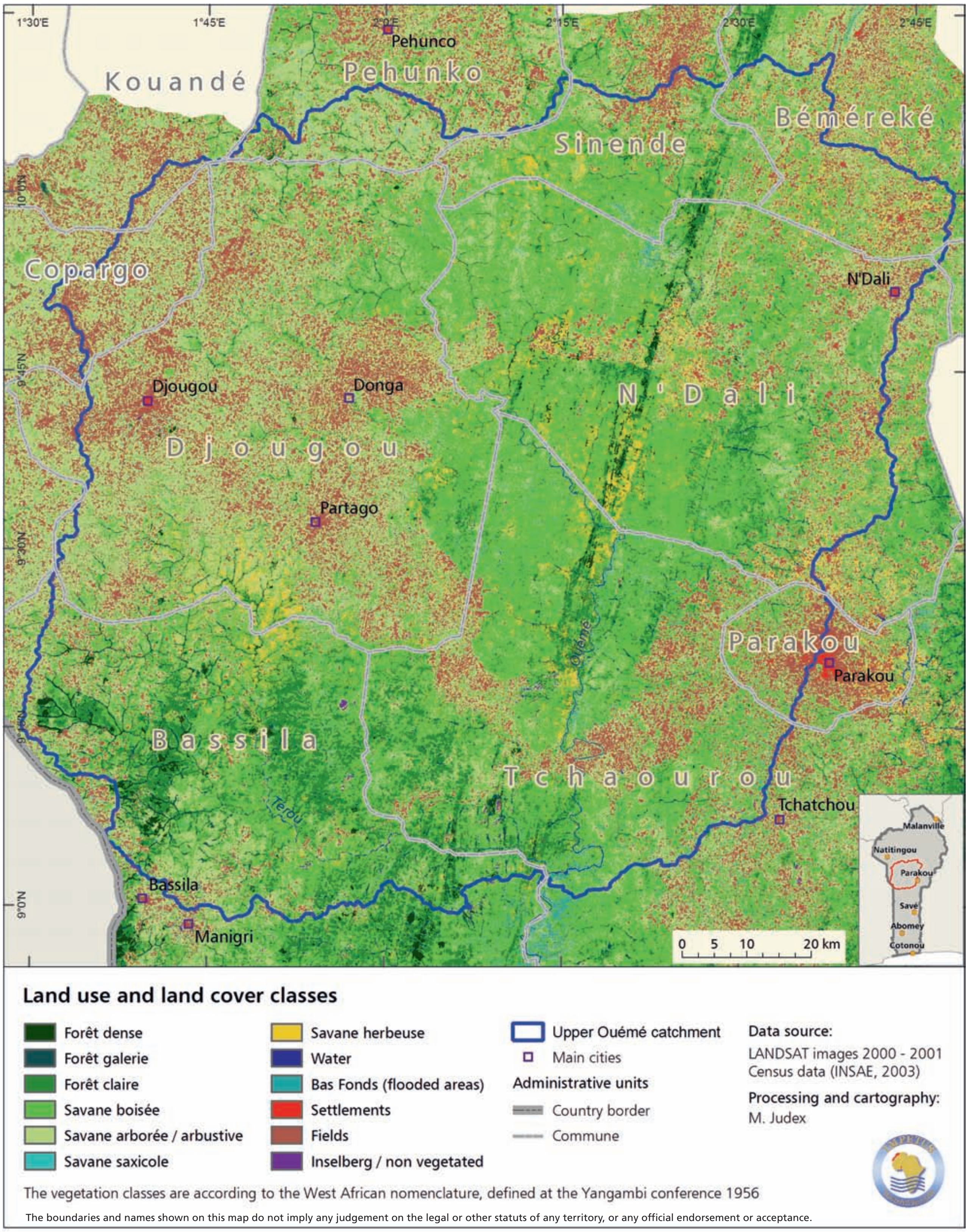

***Fig. 2:** Map of land use and land cover in central Benin*

References

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39

Land Use Dynamics in Central Benin

Michael Judex, Hans-Peter Thamm and Gunter Menz

In central Benin, strong land cover and land use changes can be observed due to rapid population growth and expansion of agricultural areas. To investigate these changes, land cover and land use information for different time periods were obtained from satellite images and compared. The analysis highlights intra-annual vegetation dynamics as well the locations and amounts of anthropogenic land use changes.

Data used

To obtain and explain information on land use / land cover changes, observations from different time periods are required. In addition to land cover data from the year 2000 (acquisition date: 26th October, see preceding page), satellite data from 1991 (acquisition date: 13th December) were classified into the same land use categories.

Changes in land use

A comparison of the years 1991 and 2000 shows very strong changes (see Tab. 1). An increase in agricultural areas and settlements is obvious. *Communes* with high absolute population growth, like Tchaourou and Djougou, display an increase in agricultural area of 36 % and 40 %, respectively. In addition, the vegetation reveals strong intra-annual vegetation dynamics. This is due to strong phenological change in the course of the wet and dry seasons. With the onset of the dry season, grass vegetation becomes dry and many trees lose their leaves, a prerequisite for the widespread bush fires that affected 35 % of the area of the Upper Ouémé in 1991 (until 13th December). Figure 1 shows examples of these changes in LANDSAT satellite images. These effects make it difficult to derive the same vegetation patterns (and areas) from satellite images taken at different dates and seasons.

Some vegetation units, like gallery forests, change their shape, and their contrast to the neighbourhood vegetation is altered. Other vegetation types, like bush or wood savannah, are affected by bush fires and are no longer distinguishable. These circumstances are important when interpreting Tab. 1.

Regional dynamics

Land use changes show different dynamics in different regions (Judex, 2008). Figure 2 (map A) displays the increase in agricultural area per *Arrondissement*. In every *Arrondissement*, the agricultural area is increasing, but at different rates. High rates of change are generally found either in regions with high population growth (e. g., Donga) or in regions with large available land resources (e. g., Bassila).

The expansion of agricultural areas occurs mainly at the expense of savannah or forest areas. To detect hot-spots of such deforestation, a pixel-by-pixel analysis was performed, with results shown in Fig. 2 (map B). In densely populated areas like Ouaké or Copargo, the fraction of new agricultural area established by deforestation is very low, as very few forest areas remain for conversion. In these areas, a typical bush-fallow rotation system is found. In contrast, high deforestation activities are found at the forest borders relatively far from larger towns. Especially high deforestation activity can be observed

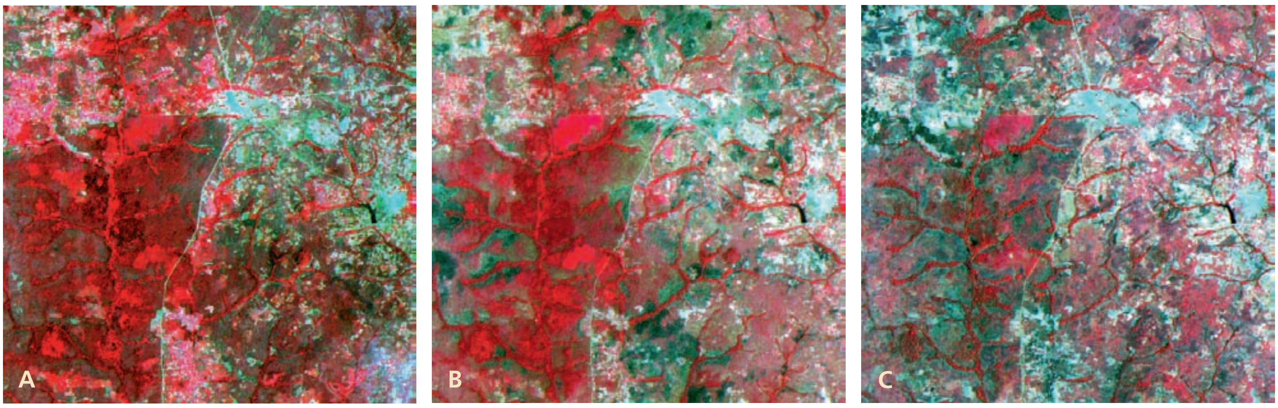

Fig. 1: *Example of intra-annual vegetation dynamics in the region of Bassila. LANDSAT false-colour images from A) October; B) December; C) March 2000 / 2001. Green vegetation is in red and burned areas in dark green.*

Tab. 1: *Land use changes from 1991 to 2000 in hectare for some* Communes *in central Benin.*

	Tchaourou		N'Dali		Bassila		Djougou	
	1991	**2000**	**1991**	**2000**	**1991**	**2000**	**1991**	**2000**
Forest & dense Savannah	351,219	431,782	221,881	225,521	377,605	431,917	100,955	99,625
Savannah	54,965	159,293	37,391	119,470	23,213	116,089	71,270	213,653
Settlement	139	424	106	289	68	135	237	672
Agricultural area	38,838	60,452	24,046	30,363	16,843	23,918	47,706	79,483
Burned area	208,603	0	92,595	0	154,793	0	173,403	0

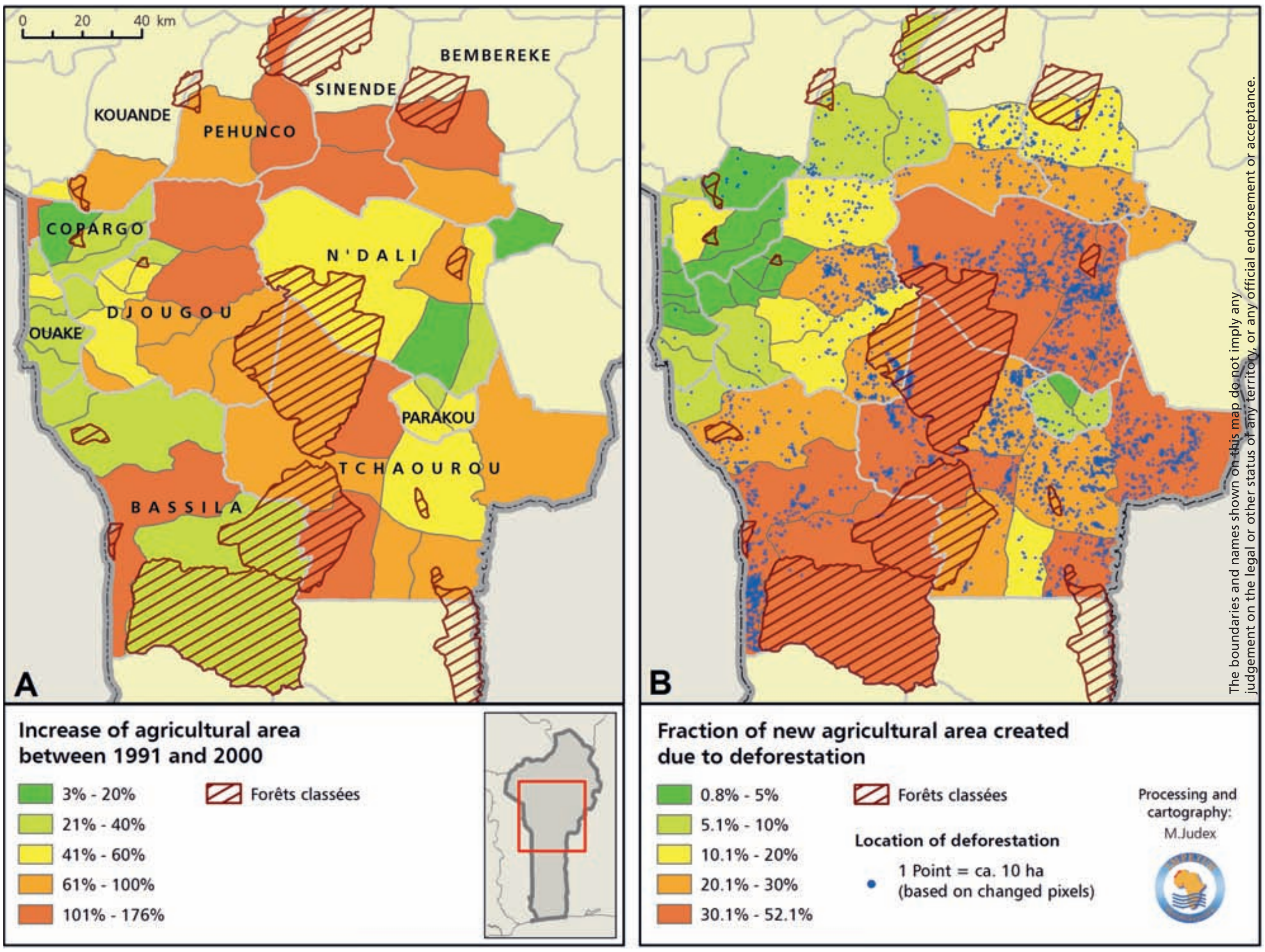

Fig. 2: *Land use dynamics due to expansion of agricultural areas. Data derived from LANDSAT images from 13.12.1991 and 26.10.2000. The areas of the protected forest are included in the given statistics.*

around the *Forêt Classée de l'Ouémé Supérieure*, but the protected area is largely respected except for one location at its western border. This analysis demonstrates the high rates of land use and land cover changes in the area as well the capabilities of remote sensing techniques to capture these dynamics.

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Modelling Scenarios of Land Use Change

Michael Judex

In order to project future developments of the rapid land cover and land use in the Upper Ouémé region, a land use change model is necessary. We used the CLUE-S land use change model framework and parameterised the land use / land cover data derived from satellite images and socio-economic data. With this approach, we calculated several future scenarios of spatial land cover / land use changes for the Upper Ouémé region.

The model aproach

From a broad range of different land use model approaches, we chose the CLUE-S framework (Conversion of Land-Use and its Effects at Small regional extent, Verburg et al., 2002) because of its dynamic and multi-scale potential, its spatially explicit raster-based procedure and many successful applications in tropical regions. The CLUE-S framework allows us to simulate a set of scenario assumptions regarding land use changes. The most important input parameters are a set of spatially explicit driving forces of land use (change), some conversion rules, area restrictions and expected change of the area of the land use categories.

To model future land use changes, one must know which factors drive the spatial distribution of land use. In this study, we used: population density, distance to roads, villages and main cities, land tenure, suitability of soils for agricultural production and topographic parameters. With these driving forces, spatial probability maps were calculated for each land use category by logistic regression (Fig. 1). The other parameters were determined with detailed user knowledge of the land use dynamics of the study area (Judex, 2008).

The spatial resolution of the input data was 250 m x 250 m, as the full resolution of the original land use data (30 m x 30 m) was too detailed for the modelling approach.

Model performance

The model was calibrated for 1991 and 2000 based on available land use data derived from satellite images. The calibration aims to fit the observed land use changes from 1991 to 2000 as closely as possible. The model performance was calculated with the fuzzy kappa statistic. The comparison of the modelled result of the year 2000 with observed land-use for the category agricultural land use and other land use gives a kappa of 0.36; for 86 % of the area the model result matches observations (Judex, 2008).

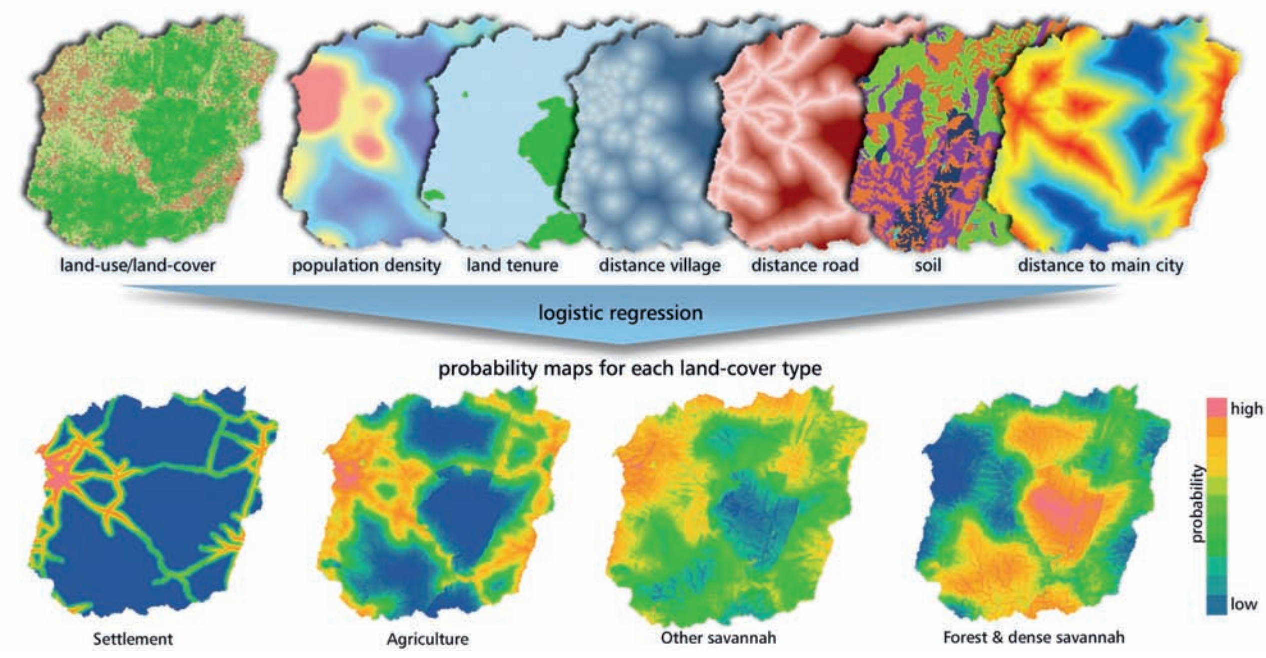

Fig. 1: *Calculation of probability maps for land use classes using logistic regression and spatial driving forces.*

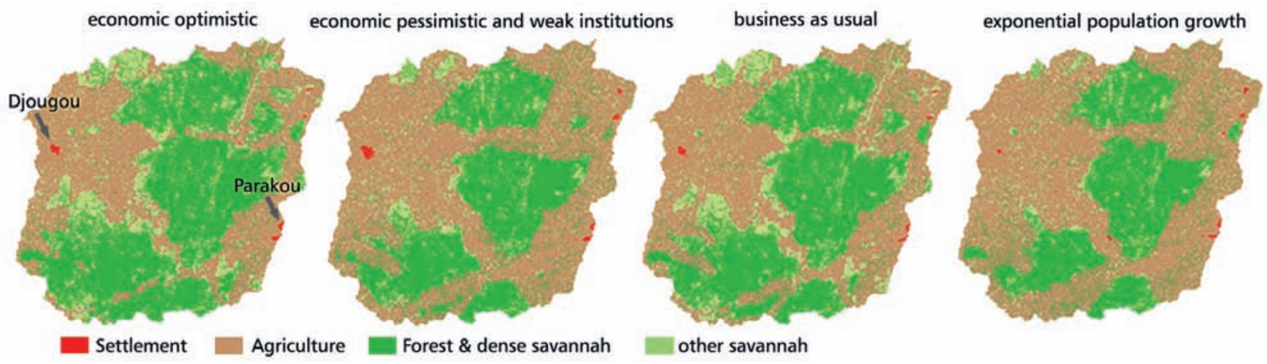

Fig. 3: Land use model results (Upper Ouémé region) for the year 2025 for four different scenario assumptions. (In order to compare with land use data from 2000, see first image in Fig. 1.)

Scenarios of future change

The boundary conditions of the modelled scenarios are geared to the IMPETUS baseline scenarios, which have a time horizon of 2025. Therefore, we defined an economically optimistic scenario with strong institutions and resource-saving management, an economically pessimistic scenario with weak institutions, and a business as usual scenario. Additionally, the business as usual scenario was calculated with exponential population growth. As the CLUE-S framework could not be linked to an economic model to estimate the total amount of land use areas in each category, our own assumptions were made (Judex, 2008).

The settlement area will increase by 4 % per year (based on historic data), except in the economically pessimistic scenario, where the growth rate will increase by up to 6 % until 2025. The agricultural area is calculated based on population growth (from demographic projections), assumptions on area use per capita, and intensification of farming systems. The results for the different scenarios are shown in Fig. 2.

The rate of deforestation due to agricultural expansion is calculated from past observations by satellite image analysis: 47 % of new agricultural areas will be created by deforestation of forest and dense savannah. In the economically optimistic scenario, the decrease is only about 30 % by 2025.

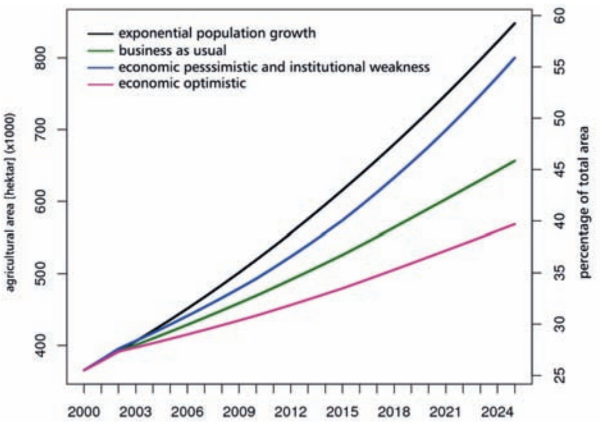

Fig. 2: Increase of agricultural area for different scenarios.

Model results

Figure 3 shows a subset of the yearly results of the dynamic simulation model. Every scenario shows an increase in agricultural area and a loss of natural vegetation. In areas with high population density (mostly around cities), all available space will be converted to agriculture in the near future. Further land use conversions are found along roads near forest areas, where the probability of agricultural activity is high. This will lead to a high rate of deforestation, especially in these areas. If the boundaries of the protected forests (public ownership) are not controlled, the small ones will likely be converted to agricultural areas. This is the case in the economically pessimistic scenario. However, the main task to slow down rapid land cover changes is adapted intensification of agricultural production, i.e. an increase in the yield per area unit, along with sustainable land use planning.

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41

Application of a "Low Cost" Ultra Light Air Vehicle for Spatial High Resolution Remote Sensing

Hans-Peter Thamm

To meet the demand for aerial photos at a very high spatial or temporal resolution, a comparatively cheap and robust, remotely controlled, ultra light air vehicle (UAV) was used. It was applied successfully to investigate vegetation dynamics, development of settlements, erosion, and other land surface processes. It is an interesting tool, especially in developing countries.

Problem

In Benin, like in many other developing countries, there is an increasing demand for aerial photos with a very high spatial and/or temporal resolution (e.g., to investigate vegetation or settlement dynamics, soil erosion, bushfires, and other processes).

Very often, however, specially equipped airplanes are not available or they are too expensive to hire. Thus, there is a demand for a system that takes aerial photos at the desired spatial and temporal resolution. For easy application it must be robust, easy to transport, and safe to operate.

The ultra light air vehicle

As one solution, a remotely controlled UAV (ultra light air vehicle), was used. It has a tube frame with a 5.5 hp two-stroke engine and a parachute that serves as a wing (Fig. 1). This allows for slow and stable flight and guarantees high safety in case of a failure. The sensor carrier system is gimbal-mounted, so the images are always at nadir (Fig. 1). For easy transport the drone can be dismantled and carried in a box. The overall weight of the system is about 12 kg with a payload of around 5 kg. A maximum flight speed of 30 km/h can be reached, which restricts the use of the drone to wind conditions lower than 6 m/s. The maximum flight level is 4000 m and the operation distance can be up to 5 km. The length of the runway is dependant on the wind conditions and varies between 5 m and 25 m (Fig. 2). The system is very easy to operate so the operator does not need extensive training.

Different sensors can be used to monitor the earth surface. For optical images, high quality consumer digital cameras (10 Megapixels) are applied, but multi-spectral or thermal cameras can be utilised as well. Real time transmission of the GPS position and the live image of the field of view of the camera to the operator ensure easy navigation of the UAV.

Applications

In Benin, the UAV was used successfully for obtaining ground truth for classification of land use and land cover and to distinguish different tree species. In addition, settlement dynamics and road patterns were assessed. The derivation of digital elevation models at a very high spatial resolution (up to 7 cm resolution in height) was possible (Fig. 5). In co-operation with the GTZ (German Development Service), an evaluation of measures for land conservation was carried out. Even mapping archaeological sites were performed with the UAV.

The images from the UAV can be stitched into large mosaics (Fig. 3) and processed with normal image processing programs. If the required photogrammetric precision is not extremely high, even cheap shareware programs can be used. Of great value is the ability to assess changes between two time stamps with different change detection techniques (Fig. 6).

Summary

The UAV is a very useful tool to obtain aerial photos for manifold tasks in developing countries. It is comparatively cheap, robust, easy to operate, and safe. It can substitute for time consuming field work and expensive satellite images.

Further reading

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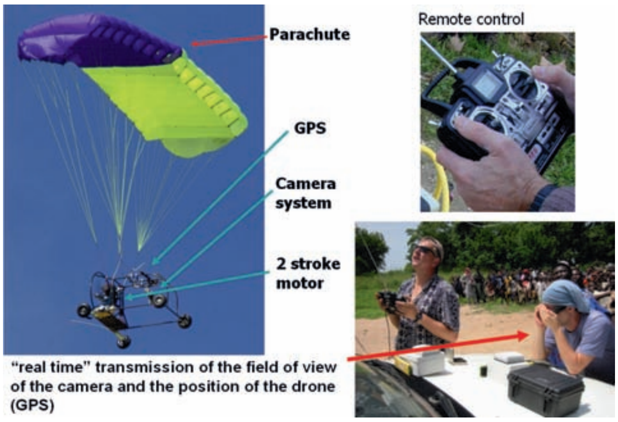

***Fig. 1:** Elements of the ultra light vehicle.*

***Fig. 2:** UAV ready to start. The runway can be prepared easily.*

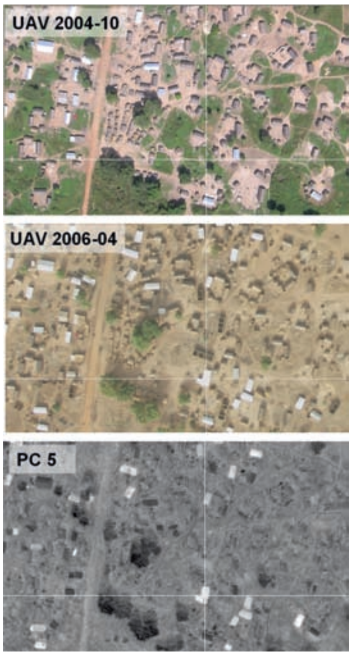

***Fig. 6:** Settlement dynamics of the village Kpawa between October 2004 and March 2006. The upper image shows the village in October 2004 the image in the middle was taken in April 2006. The image on the bottom visualises the changes between both images. Bright spots represent new houses with tin roofs. This analysis was performed with a special adapted change detection technique (principal component).*

***Fig. 3:** Overview over an inland valley near Quake. Images mosaiced from several UAV images.*

***Fig. 4:** Orthophoto of a rural area near Quake. Rice and yams fields can be seen. The round structures are threshing places for rice.*

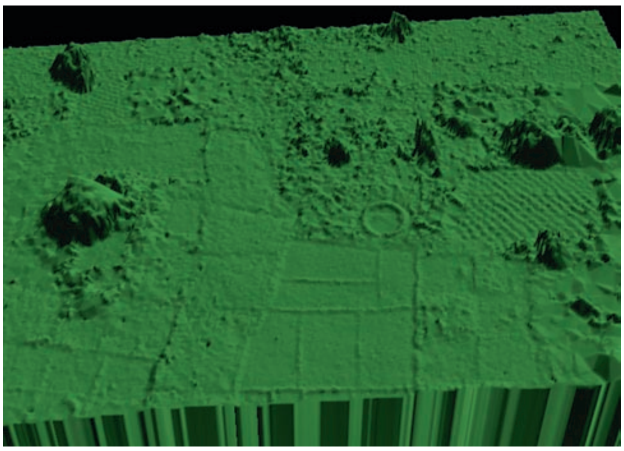

***Fig. 5:** Digital elevation model derived from images taken with the UAV. The precision in height is 7 cm. This figure covers the same area as shown in Fig. 4.*

42

Vegetation trends in Benin (1982 – 2003)

Julia Röhrig

Time series of NOAA AVHRR NDVI data are compared to rainfall data to analyse the state of the vegetation productivity and vegetation trends during 1982 and 2003. Remote sensing is suitable for monitoring land performance as biophysical indicators can be derived efficiently in time and cost on different spatial and temporal scales.

Methodology and Data

Rain use efficiency (RUE) is a common indicator to determine land degradation and trends of vegetation in semi-arid and semi-humid landscapes (e.g. Hountoundji et al., 2006). The indicator is based on a strong relation between vegetation dynamics and rainfall. For Benin, we used the normalised difference vegetation index (NDVI) from the NOAA Global Inventory Monitoring and Modelling Studies (GIMMS) to analyse vegetation cover and productivity between 1982 and 2003. For Western Africa, the more recent 1 km SPOT VEGETATION NDVI product is less appropriate than the AVHRR data due to an insufficient cloud screening of SPOT suppressing rainy seasons (see Klein and Röhrig, 2006; Fenshold et al., 2007). The spatial resolution of the data is 8 km x 8 km. To calculate rainfall amounts, downscaling results of the atmospheric model REMO were implemented (↗5). Yearly sums were calculated for NDVI (iNDVI) and rainfall (yrain). To investigate whether this method can be transformed to more humid tropical regions we first carried out correlation analyses of yrain and iNDVI. Table 1 confirms a general high correlation between rainfall and vegetation for all parts of Benin (cf. Klein and Röhrig, 2006). Furthermore, iNDVI images show highest values for forests and parts of the south, which indicates that the GIMMS data set does not create fundamental saturation problems in Benin. Although it can influence the result indicating wrong negative trends.

***Tab. 2**: Correlation coefficients of iNDVI and yearly sums of rainfall (yrain).*

	250 sites (random)	South Benin	Central Benin	North Benin
r	0.84	0.82	0.91	0.81

Rain use efficiency was then calculated for each site and trends from 1982 to 2003 examined. We used the yearly ratio of iNDVI/yrain to determine the RUE. Trends were determined by linear regression of the ratio (dependent variable) and time (independent variable). Based on the Student's t-test, the regression slope can be mapped into seven classes indicating different statistically significant trends (Eklundh and Olsson, 2003, Hountondji et al., 2006). For Benin, we labelled classes as 'strong' trends (positive or negative) if the T-value of the slope exceeded the 0.025 p-value of either tail of the distribution. If the T-value was between the 0.025 and 0.05 p-value or between 0.05 and 0.15, the trends were 'medium' or 'weak,' respectively. All other sites were classified as 'no trend' showing no statistically significant development for this time period.

Trends of vegetation productivity in Benin (1982-2003)

Figure 1 illustrates that about half of the country shows no statistically significant trend for the iNDVI/rain-ratio (RUE) since 1982. Only separate sites in the southeast have significant positive trends. The majority of the remaining half, however, is characterised by negative trends. For nearly 10% of all sites in Benin, we determined statistically strong negative trends. These areas have experienced continuous declining vegetation productivity, which are not caused by decreasing rainfall sums. They are situated mainly in the central or northern Benin. These are often areas characterised by low or medium population density but high population growth rates. This corresponds very well with observable flows of migration. Many people migrated from the degraded regions in the west and south into areas with rather low population density. Here, natural vegetation is transformed sustainably into new settlements and fields. Such expansion of agricultural activities onto marginal sites is of particular interest as the risk of severe land degradation is particularly high.

Surprisingly, medium to strong trends are calculated also for some protected areas. Some of these trends maybe artificial ones caused by saturation or cloud problems as well as the coarse resolution of the data. Nevertheless, real vegetation trends can be found also in these areas like regular fires to guarantee visitors good sights of wildlife in some parts of the Pendjari National Parks along the border with Burkina Faso. In addition, rising numbers of animals in the park may influence vegetation cover.

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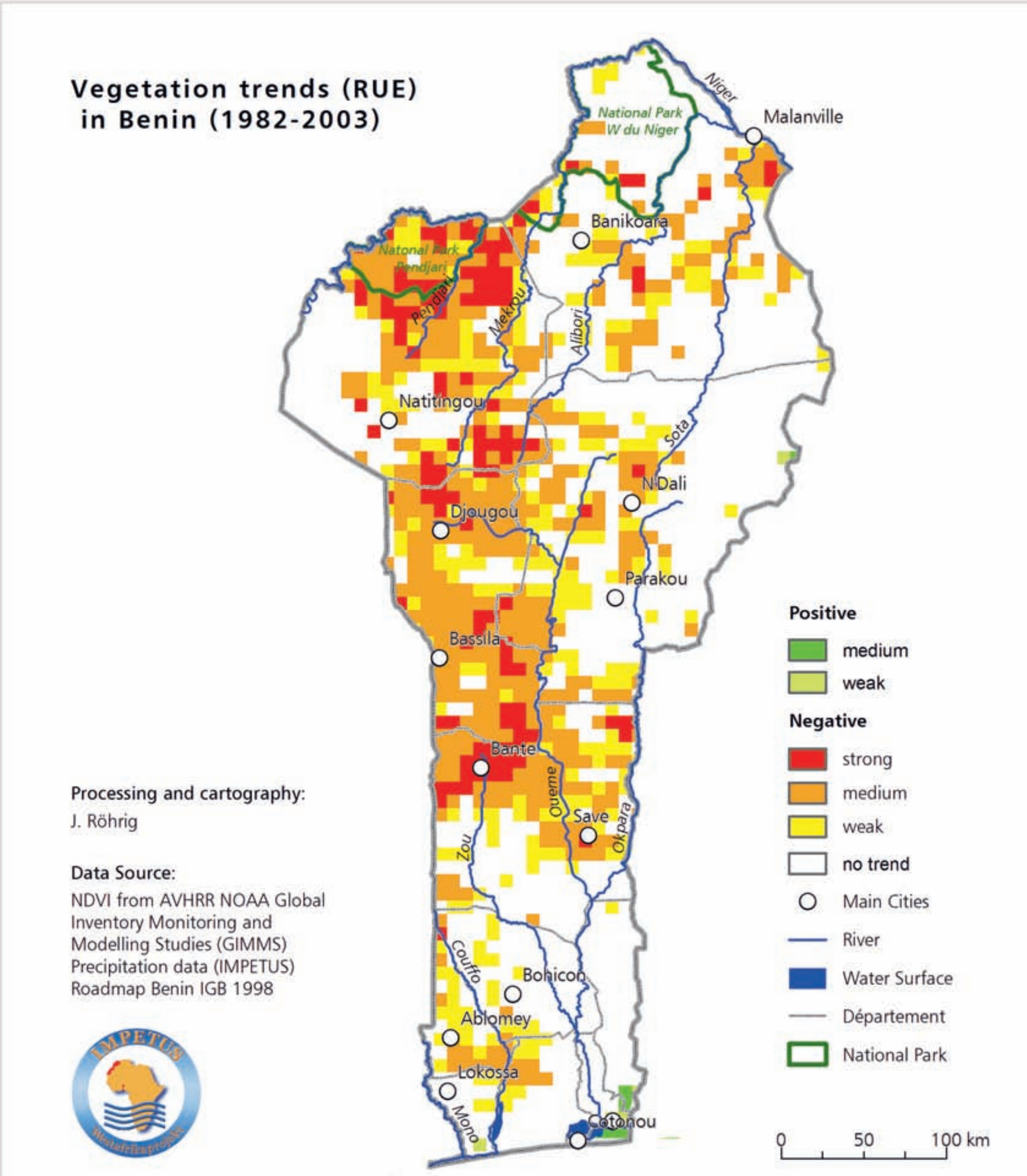

The boundaries and names shown on this map do not imply any judgement on the legal or other status of any territory, or any official endorsement or acceptance.

***Fig. 1**: Trends of the iNDVI / yrain ratio (RUE) between 1982 and 2003*

43

Natural Agricultural Marginality in Benin

Julia Röhrig, Claudia Hiepe and Malte Diederich

Globally, peasants are forced onto marginal lands due to growing population and a lack of alternatives to ensure food security. Marginal agricultural sites, however, are characterised by various environmental constraints limiting agricultural land use. Furthermore, marginal sites are particularly prone to land degradation if used agriculturally. Thus, identifying marginal sites is crucial for sustainable land use and conservation of natural resources.

The approach

Cassel-Gintz et al. (1997) introduced a marginality index for agricultural land use as an early warning indicator for detecting naturally based marginal agricultural sites. In this context, marginal areas are characterised by a low potential of the biophysical land and a fragile environment. The marginality index for agricultural land use was originally developed on a global scale. Global data, however, with a spatial resolution of 0.5° (at the latitude of Benin ca. 50 km), can give only a very general idea about the risk of degradation caused by agricultural activities, and provides little information for national decision makers. Thus, investigations have been undertaken to regionalize this approach for Benin at a spatial resolution of 1 km x 1 km using influencing factors in a higher spatial resolution and an adapted fuzzy logic based algorithm (see Fig. 1).

Data

In order to evaluate the marginality index, several natural constraints limiting agriculture were quantified and summed into one integrative index.

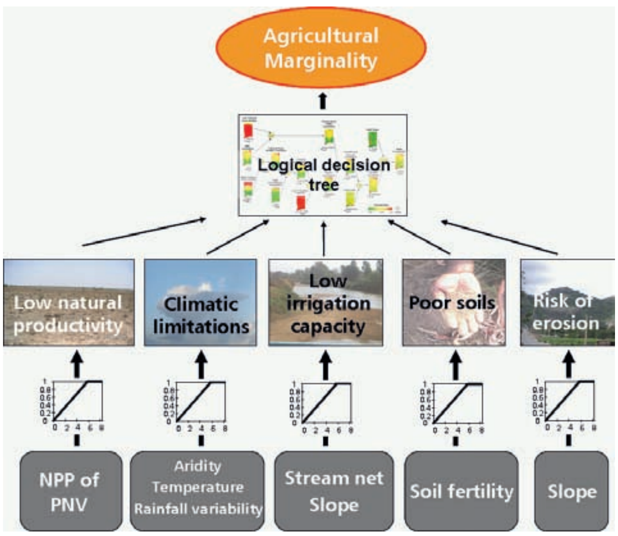

Fig. 1: Conceptual framework for determining a marginality index for Benin.

Table 1 summarizes the chosen indicators and data for the regionalization. Taking into account the available database for Benin and the needs of stakeholders, a number of slight modifications were necessary.

Tab. 1: Indicators and data used to determine the marginality index for Benin.

Indicators	Data
Potential natural vegetation cover (PVEG)	Potential biomass density (PBD) (Brown & Gaston 1996)
Temperature and Light (TEMP)	Actual and potential evapotranspiration (IMPETUS)
Length of growing period (LGP)	Rainfall data (IMPETUS)
Rainfall variability (RAINV)	Rainfall data (IMPETUS)
Potential irrigation capacity (IC)	SRTM (Shuttle Radar Topography Mission) (Farr & Kobrick 2000)
Soil fertility (SF)	Soil map of Benin by ORSTOM (Volkoff 1976)
Slope (SL)	SRTM (see IC)

Methods

For the processing of the input data and the determination of the index, fuzzy logic was used. The first step in calculating the marginality index was fuzzifying the indicators (cf. Fig. 1). For each site (pixel), a degree of membership of linguistic categories (low, high, etc.) was set up in relation to its contribution to the marginality index ($0 \leq \mu \leq 1$) (Cassel-Gintz et al., 1997, Zimmermann, 1991). A degree of 0 indicates that there is no limitation on agricultural land use, whereas 1 indicates that natural constraints are too high for agricultural land use in general. Between these two values, a mostly linear membership function was defined. The definition of the membership function was performed empirically. In a further step, these fuzzified variables were combined using a logical decision tree. Within the decision tree, all arguments for or against agricultural marginality were summed using fuzzy logic operators.

To help national decision makers, input data and the calculation algorithm were implemented within the computer-based Spatial Decision Support System (SDSS) 'AGROLAND'. With the SDSS, the user is able to visualize and analyze agricultural land resources based on the marginality index (cf. Laudien et al., 2006).

Natural agricultural marginality in Benin

The map in Fig. 2 shows a spatially detailed pattern with values ranging from 0 to 1. Thus, Benin contains sites with very good biophysical conditions for agricultural land use, but also regions where high natural constraints make them prone to land degradation if used agriculturally. 20 % of the area of Benin has at least slight natural constraints (marginality values of up to 0.2), while nearly 40 % shows values higher than 0.6. The north is especially characterized by high marginality values due to a short rainy season, temperature constraints and poor soils. In general, the conditions are moderate, as demonstrated by an average value of 0.54. This is mainly due to rather poor soils in Benin. As in many tropical countries, the chemical fertility is low. Hence, the use of nutrients or regular periods of fallow are advised and necessary for cultivating the soils. In additional, natural landscape features, such as the mountainous Atacora region in the north-west, are clearly observable. At the large scale, crucial biophysical parameters limiting agricultural production in Benin are soil fertility and the length of the growing period.

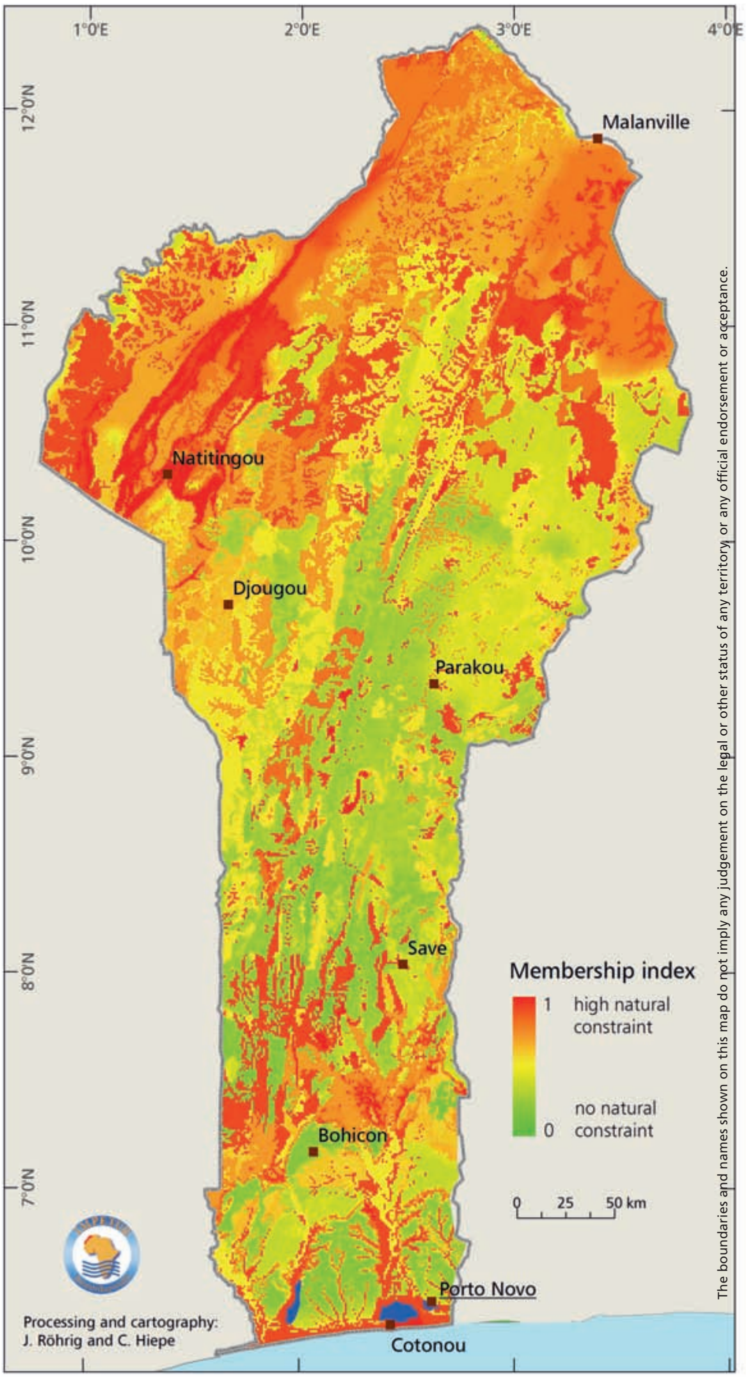

Fig. 2: The natural marginality index of Benin

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44

Bushfire in Benin

Hans-Peter Thamm

Bushfires are an important influencing factor of the eco-systems of the savannah regions in West Africa. Despite the ongoing discussion about the role of natural and anthropogenic bushfires, man has used fire for manifold purposes for centuries. With increasing population, the frequency of bush fire is growing. This can have strong impacts on the ecosystem and can lead to soil degradation and loss of biodiversity. Therefore, proper bush fire management is necessary.

Introduction

Bushfires have been a part of the natural eco-system of the savannahs in Benin for millennia. Among botanists, a discussion is ongoing about whether the savannah vegetation in central and north Benin is the climax state due to natural bush fire.

In Benin, since men have had the ability to control fire they have used bushfires for many purposes. Fires are lit for preparing fields, to trigger the growth of fresh grass for cattle farming, to get rid of pests, for hunting, and for various other reasons.

The main bushfire period is during the dry season from about October to March / April, but some fires are lit even in the rainy seasons as soon as there is some burnable material available. The fires burn mainly the understory, not affecting the vitality of the trees (Fig. 1).

The use of fire is an appropriate technique to cultivate land with little manpower, but increasing population density has led to a higher frequency of fires and greater areas being affected by the fire. In some parts of Benin, more than 70 % of the land area is burned during a fire season. Figure 2 shows the spatial pattern of the fires derived from MODIS satellite data for the dry season of 2006 / 2007.

The drawbacks of bushfires cause serious problems. Bushfires decrease the air quality. The soil fertility is diminished because biomass is burned and not incorporated in the soil, which results in little humus content. In addition, the nutrients concentrated in the ash of burned vegetation are commonly blown or washed away. In particular, the “late fires” at the end of the dry season have very negative impacts regarding soil fertility.

Another negative effect is the fact that fires can get out of control and destroy fields and plantations.

Fire mangagement

To minimise some of the negative effects of bushfires on soil fertility, the legislation of Benin forbids the use of bush fires after the 15th of December (“feu tardif”).

However, often in remote areas of Benin the national laws and regulations are not respected. Thus, there is a demand for sound information about the spatial and temporal patterns of bush fires in Benin. To provide this information, IMPETUS established a bush fire monitoring system based on daily MODIS satellite images (Fig. 2). It allows the analysis of the occurrence of bushfires at a high temporal resolution and gives decision makers a sound information base.

The successfulness of bushfire management was proven in a common project of IMPETUS with the GTZ / ProPGTRN in Boukoumbé (Atacora). Figure 3 shows the occurrence of fire in and around an intervention zone (yellow and red dotted line) for the fire period of 2001 / 2002. This analysis was derived from LANDSAT satellite images. Early fires before mid-December are marked in green and yellow. Later fires are marked in red. Within the zone where the use of fire was prohibited by agreements, only a small area was affected by fire (red zones in the west), whereas beyond the borders of the area fires have been frequent. This shows that an efficient control of bushfires is possible. IMPETUS is setting up a monitoring and decision support system for managing bushfires.

Fig. 1: *Bush fire in the HVO. Normally the bush fire burns only the dry grass and understory. The trees are mostly not affected by the fire.*

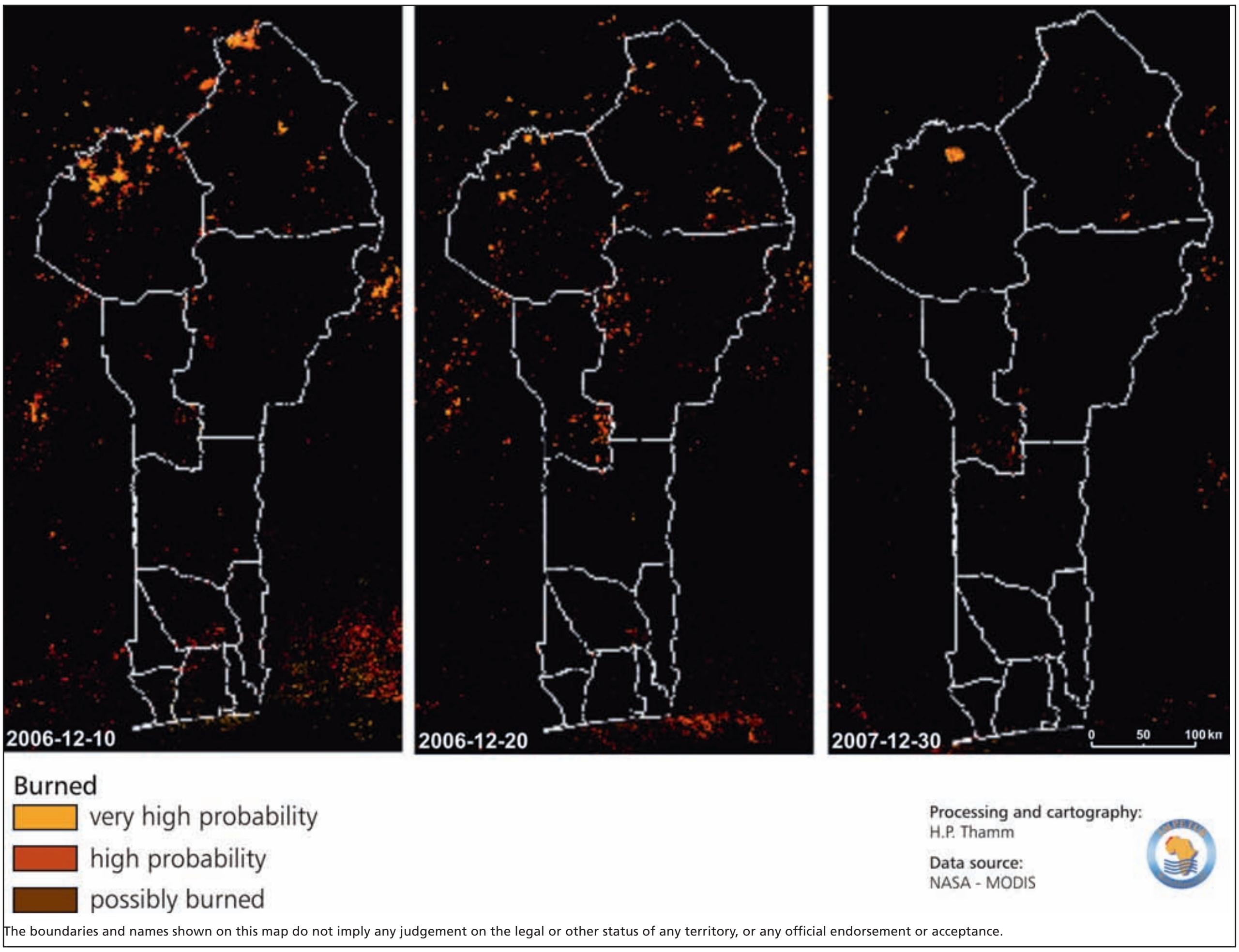

Fig. 2: *Distribution of a bushfire in Benin for three 10 day periods. Derived from MODIS 250 m data with automated processing.*

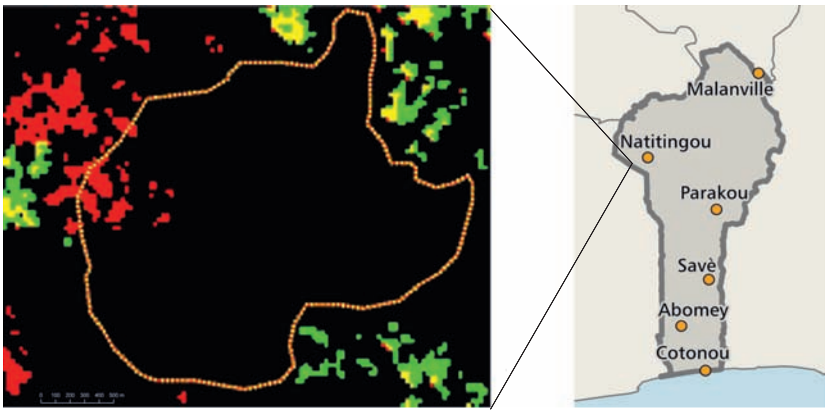

Fig. 3: *Occurrence of fire for an intervention zone in Boukoume (Atacora, North West Benin), where fires were not allowed for the fire period 2001-2002. Green and yellow show early fires (before the 15th of December); red show late fires (after the 15th of December). Only a small part of the zone was affected by fire, whereas outside of the zone big zones where burned. Result of an analyses of LANDSAT images.*

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45

Survey of Inland Valleys in the Upper Ouémé Catchment

Simone Giertz, Gero Steup, Luc Sintondji, Felix Gbaguidi and Sarah Schönbrodt

The rapidly growing population in sub-Saharan Africa needs increased food production. Inland valleys offer an extensive but underexploited potential for agricultural production due to their higher water availability, lower soil fragility and higher fertility compared to upland areas. Due to high population growth and shortage of available cultivable land, the exploitation of inland valleys will only become more important to this region's future. In order to evaluate the agro-potential of inland valleys of the region, we carried out a detailed field survey of physical and socio-economic properties of inland valleys in the communes of the Upper Ouémé catchment. This inventory is part of a multi-level approach using GIS, remote sensing, field surveys and interdisciplinary modelling to evaluate the agro-potential of inland valleys. The results will be implemented in an information system to be made available to decision makers in Benin.

The survey

As no adequate database was available for inland valleys of the Upper Ouémé catchment, we carried out a survey to determine their physical properties and socio-economic situations. Studies were done in cooperation with the *Cellule Bas-Fond*, the local authority for inland valley management in Benin.

While the *Communes* N'Dali, Djougou, Parakou, Bassila and Tchaourou were surveyed completely, only the parts lying within the Upper Ouémé catchment were taken into account for the *Communes* of Copargo, Sinende and Bembéréké. The respective inland valleys were identified by the staff of *Cellule Bas-Fond* through personal interviews with local authorities (*Chef de village, Délégué*) in each village of the target region. With the assistance of local farmers, the extent of each inland valley was mapped using GPS. For each inland valley, a detailed questionnaire was completed to determine aspects of geomorphology, soils, hydrology, ethnic affiliation of the farmer, exploitation of the inland valleys, management structures, marketability of products, and so on.

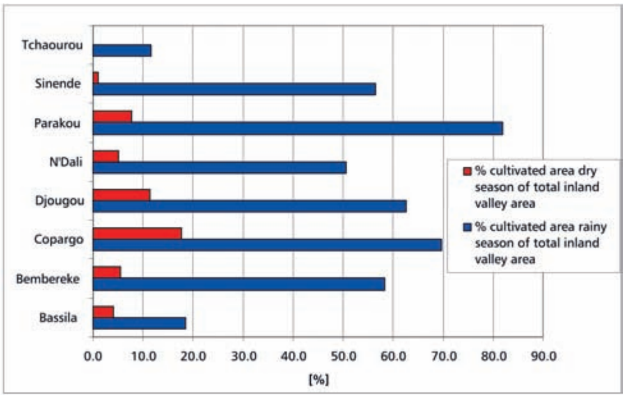

Fig. 1: *Percentage of cultivated area of the available surveyed inland valley area per season and commune.*

Results

During the survey, 817 inland valleys were located in the target region with a total surface area of 5563 ha. Figure 2 shows the mapped inland valleys. 536 of those surveyed were already exploited, but often with only a small part used (Fig. 1). Especially in the less populated *Communes* in the south of the HVO (Bassila, Tchaourou), the exploitation rate was low. In *Communes* with a higher population density and a high degree of soil degradation, like Parakou, Copargo and Djougou, the exploitation rate was already above 60 % of the potential available inland valley surface, although in the dry season the cultivated area remained below 20 %. The main crops are rice (62 %), yams (17 %) and maize (6 %).

Inland valleys in remote areas were not taken into account with the applied methodology. In the survey the villages were used as starting point to locate the inland valleys with assistance of the local population. As villages are nonexistent in remote areas (e.g. protected forests) this approach was not applicable. Another problem was that these areas are nearly inaccessible because no roads or tracks are existing and the vegetation is very dense.

Consequently the total exploitable inland valley surface of the target region is considerably higher. In order to identify remote inland valleys, further analysis with remote sensing and GIS data must be carried out.

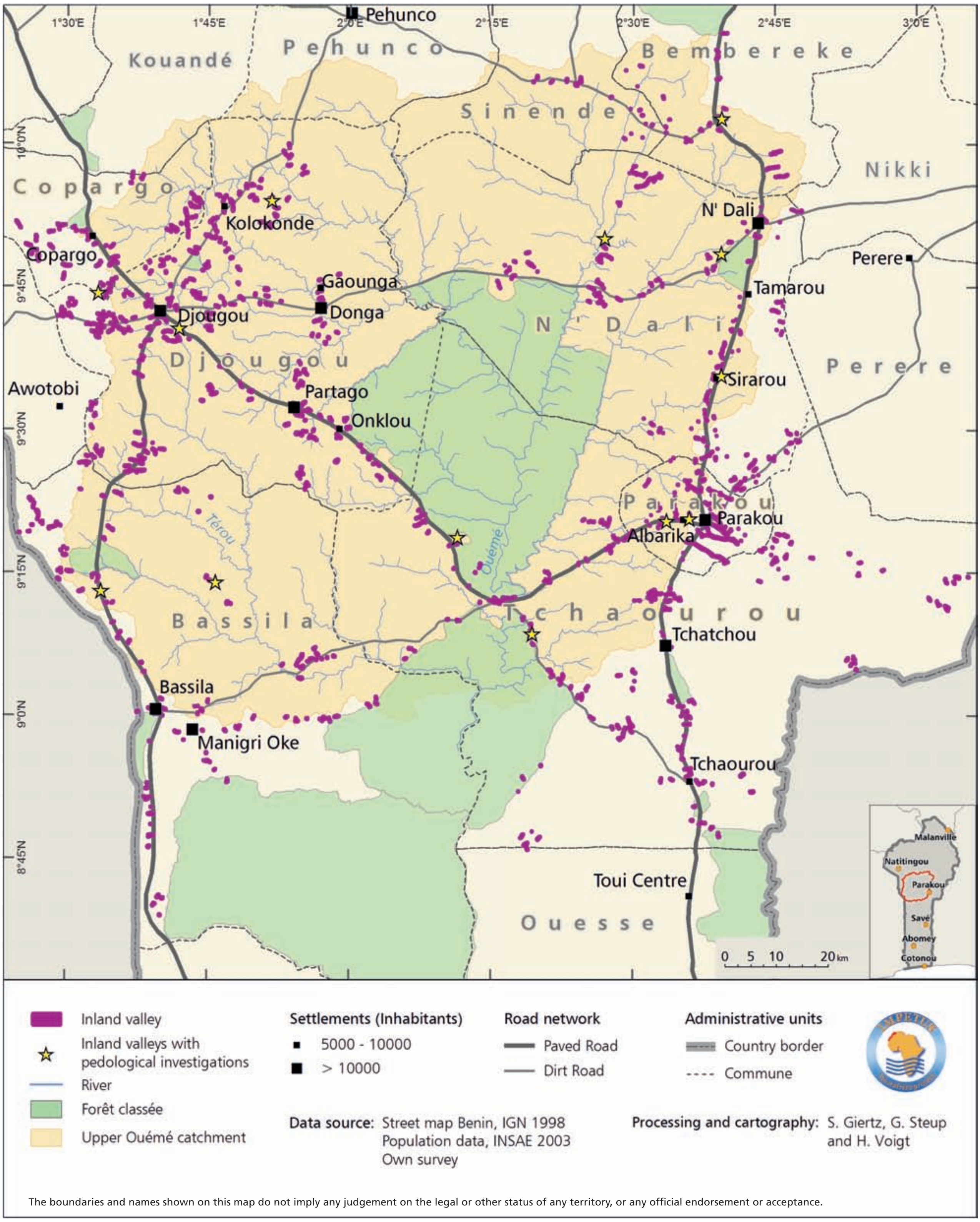

Fig. 2: Surveyed inland valleys in the communes of the Upper Ouémé catchment.

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One of the biggest markets in West Africa: Dantokpa in Cotonou.

Society and Economy – Insights into Complex Patterns

Demography: Spatial Disparities and High Growth Rates

Moritz Heldmann and Martin Doevenspeck

Demographic data for Benin are available through three national censuses from 1979, 1992 and 2002. In 2002, Benin had a total population of slightly more than 6,750,000 inhabitants (INSAE 2003), with an average density of 60 inhabitants/km² and an annual growth rate of 3.25 %. However, these national demographic figures hide spatial disparities and dynamics on regional and local scales, especially between the North and South of the country.

National trends

Since 1992, the annual demographic growth rate averages 3.25 %, which is slightly higher in comparison to only 2.8 % between 1979 and 1992. The fertility rate, though in slight decline, is currently at 5.5 % and thus is still at a high level. Fertility rates are decreasing much more significantly in the cities than in rural areas – a phenomenon that is well known in sub-Saharan Africa. The high birth rates in Benin correspond to the age structure, which is dominated by those who are under fifteen making up nearly half of the total population (see Fig. 1).

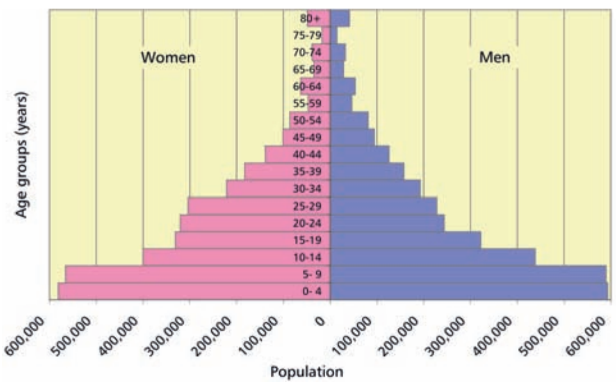

***Fig. 1:** Age Structure in Benin 2002*

The overall population density in Benin averages 60 inhabitants/km², but the population is very unevenly distributed (see Tab. 1). South Benin (238 inh./km²) has much higher population densities than Central and North Benin (27 inh./km²), which in turn, are partly characterized by higher growth rates.

South Benin

With 8100 inhabitants/km², the population density is highest in Cotonou, where one fifth of Benin's total population lives. The densities remain extremely high in the periurban surroundings of the economic capital, with about 950 inhabitants per km². Furthermore, the entire southern part of Benin is densely populated: More than 60 % of the population concentrates here on approximately 20 % of the national territory (see Tab. 1). Since few possibilities are given to earn money outside the agricultural sector, one can speak of the "Asian conditions" of South Benin's agriculture in reference to its demographic situation. These conditions refer to the non-sustainable forms of land use, a continuous reduction of cultivable land available per capita, as well as increasing landlessness and land tenure conflicts (Edja, 2001).

However, demographic growth rates in South Benin have generally been below average since 1992 – except for the periurban surroundings of Cotonou, where the highest rates are recorded to be 6 % in Sèmè-Kpodji and the national peak is at 9.5 % in Abomey-Calavi. These communes border-

***Tab. 1**: The uneven distribution of population*

Departement	Population 2002	Percentage
Littoral (Cotonou)	665,100	9.82 %
Atlantique	801,683	11.84 %
Mono	360,037	5.32 %
Couffou	524,586	7.75 %
Oueme	730,772	10.79 %
Plateau	407,116	6.01 %
Zou	599,954	8.86 %
South Benin	4,089,248	60.40 %
Alibori	521,093	7.70 %
Atacora	549,417	8.12 %
Borgou	724,171	10.70 %
Donga	350,062	5.17 %
Collines	535,923	7.92 %
Central and North Benin	2,680,666	39.60 %
Total Population	6,769,914	

ing Cotonou are, in fact, sort of Beninese dormitory towns with an increasing commuter population attracting and absorbing large parts of the migration towards the agglomeration of Cotonou.

Central and North Benin

In Central and North Benin, population density is below 70 inh./km² throughout the region, with the exception of Parakou. The lowest densities, with less than 10 inh./km², are observed in the northernmost *Commune* Karimara and westwards in Tanguita, where settlement is restricted because of the large National parks. In contrast, the northwestern *Communes* Boukoumbé and Cobli have relatively high densities, but also the lowest rates of increase, at 0.4 % and 1.9 % per year, respectively.

In contrast to these low rates of increase, other parts of Central and North Benin have some of the highest demographic growth rates of the country.

That is the case for the *Communes* Ouèsse, Bantè, Tchaourou and Bassila in Central Benin, and for Péhonko and Ségbana in the North. In Tchaourou, which had been the *Commune* with the lowest population density until the 1970s, growth rates have been consistently high for three decades, reaching 4.9 % per year. In Bassila, the strong increase of population growth has started more recently: Here, the demographic growth has doubled since the 1980s, reaching 4.8 % in 2002. Parakou is the largest town in the North and still grows dynamically with rates around 3.8 %.

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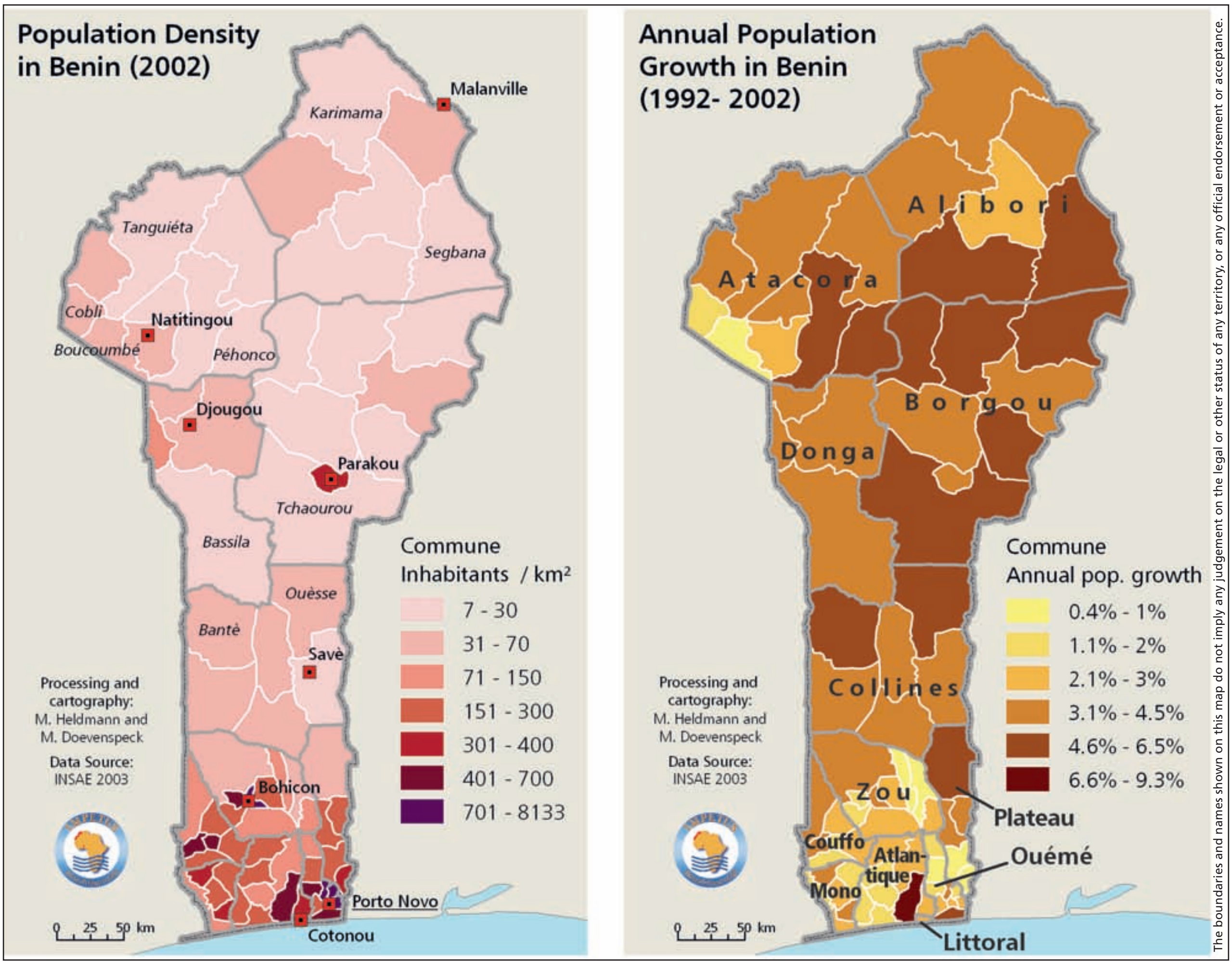

Fig. 2: Population Density (2002) and Annual Population Growth (1992–2002) in Benin

47

Population Projections for Benin until 2025

Moritz Heldmann and Martin Doevenspeck

Population projections are crucial for several reasons, particularly as a basis for planning. In the case of IMPETUS, assessing needs for rural future water supply infrastructure in Benin or pressure on natural resources requires knowledge of the future population size and distribution.

Demographic projections for Benin

Population projections are complex and require information on number and sex in the base year, as well as current data on and future assumptions about indicators like total fertility rate, age distribution of fertility, life expectancy at birth by sex, the most appropriate mortality table and the magnitude of migration.

The population and habitation census of February 2002 carried out by the National Statistic Office *Institut National de la Statistique et de l'Analyse Economique* (INSAE) provides such data. The future assumptions mentioned above have been developed with various counterparts in Benin, taking into account current data, national projections, objectives of national development policies, economic trends and various other indicators. To determine the range of plausible projections, we considered low, high, and medium variants of each assumption.

The three demographic scenarios illustrated in Fig. 1 suggest that population growth in Benin will remain one of the highest in the world. In 2025, Benin's population is supposed to average between 12.8 million and 13.5 million. The doubling time of the population varies between 28 years for the low and 23 years for the high scenarios.

Spatial disparities of Benin's future population

According to the 2002 census, Benin is characterized by an uneven distribution of its population, with 60.4 % concentrated in approximately 20 % of the national territory in the South of the country. Some parts of Central and North Benin, however, have much higher growth rates than the South, except the periurban surroundings of Cotonou where the population grows extremely rapidly.

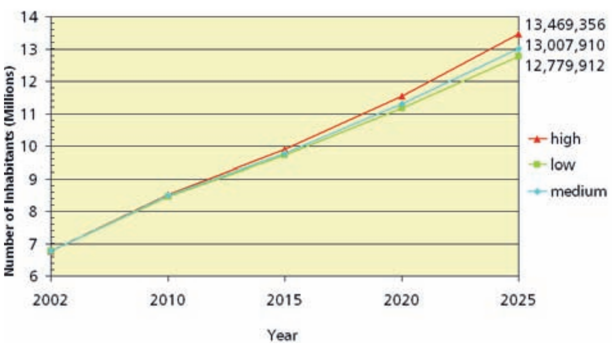

Fig. 1: *Low, medium, and high scenario for Benin's total population in 2025*

According to the medium scenario shown in Fig. 2, the spatial distribution of Benin's population will change until 2025 even though some current features persist. "Atlantique" remains the *Département* with the highest population due to the attractiveness for rural-urban migrants. But it will be followed by "Borgou" in Central Benin, which will become the most important target region for rural-rural migration.

The proportion of inhabitants living in the South will decrease from 60.4 % in 2002 to 56.9 % in 2025. However, the North-South discrepancy of population density remains characteristic for the spatial distribution of the population. The extremely high densities in South Benin will continue to exert pressure on the rural population to migrate to less densely populated regions or to the new coastal urban agglomeration extending from Porto Novo to Cotonou and its periurban surroundings in the department Atlantique.

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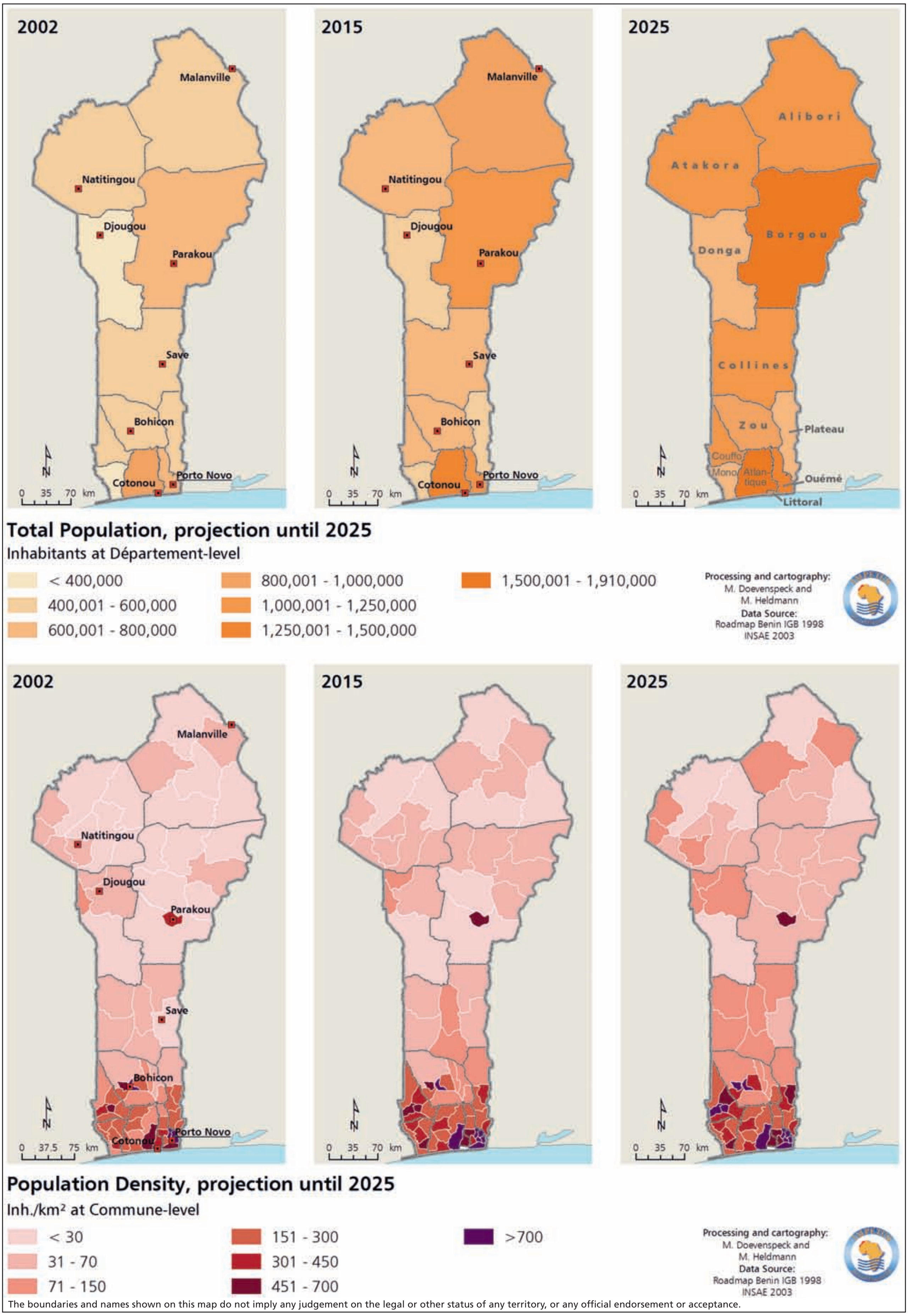

***Fig. 2**: Population projections for Benin (medium variant): Total population and population density.*

48

Religion in Benin

Kerstin Hadjer and Moritz Heldmann

Quantitative and spatial data on religion in Benin is available through the National Population Census. However, these figures have to be qualified: hybrid synergies between different religious beliefs are a major feature of religious identities in Benin. In this respect, IMPETUS research offers a more differentiated view on religious identities in Benin.

The denominations

According to the 2002 census, 42.7 % of the Beninese call themselves Christian, followed by 24.4 % Muslims. While the Christians are predominant in large parts of South Benin, North Benin is mainly inhabited by Muslims. Followers of traditional religions make up 23.3 % of the total population (17.3 % Vodoun, 6 % other traditional religion). Vodoun is mainly practised in South Benin (see Fig. 2).

Christians are subdivided into numerous denominations. Catholicism is still the largest group, but different Protestant groups and other African churches, such as the Celestial Church of Christ, have gained in prominence recently.

***Tab. 1:** The Christian population,1992 to 2002*

Census	Total Christians	Catholics	Protestants	Other Christians
1992	1,740,825	1,271,166	174,413	295,246
		73 %	10 %	17 %
2002	2,892,593	1,833,283	360,246	699,064
		63.4 %	12.5 %	24.1 %

Hybrid parallel structures

Official quantitative data (also InWEnt, ANB, CIA World Factbook etc.) can only describe a fraction of religious phenomena. Religious affiliation is described in a unilinear way: one person, one religion.

***Fig. 1:** Invocation of genies and oracle involving mirror, kauri and ink of written Koran sura*

Quantitative surveys realized by IMPETUS reveal the same tendency: At the village level, e. g. in Bougou, 89 % of household heads reported that they were Moslems, 6 % Christians and only 2 % named "other beliefs". In a neighboring village, one of the most important centers of secret societies, the category "other beliefs" was more or less absent.

In contrast, qualitative interviews and other anthropological techniques open the door to a complex world of coexistence and hybridism between religions like Vodoun, Islam, and Christianity with ancestor worship, beliefs in genies, witchcraft, and other occult practices. In sum, we met no syncretism but rather a highly symbiotic coexistence of different religious beliefs. Finally, every respondent in the mentioned villages stated a belief in the power of ancestors, genies, or sorcery causing fortune or protection. Everybody was convinced of the dangerous existence of witchcraft.

Occultism – a secret, powerful world

In Benin, secrecy concerning occult practices and beliefs is a dominant theme. People explain this attitude often by negative experiences in the context of bloody witch-hunts during the Marxist-Leninist period. Moreover, the internal structure of secret societies and the common fear of envy lead to secrecy. Diverse techniques are common, e.g. evocation, invocation, trance, ritual magic, ceremonial magic, and oracles (Fig. 1).

Occult practices have a strong impact on daily thinking, acting, and, last but not least, financial investment – independent from the origin or educational background of the people (↗54).

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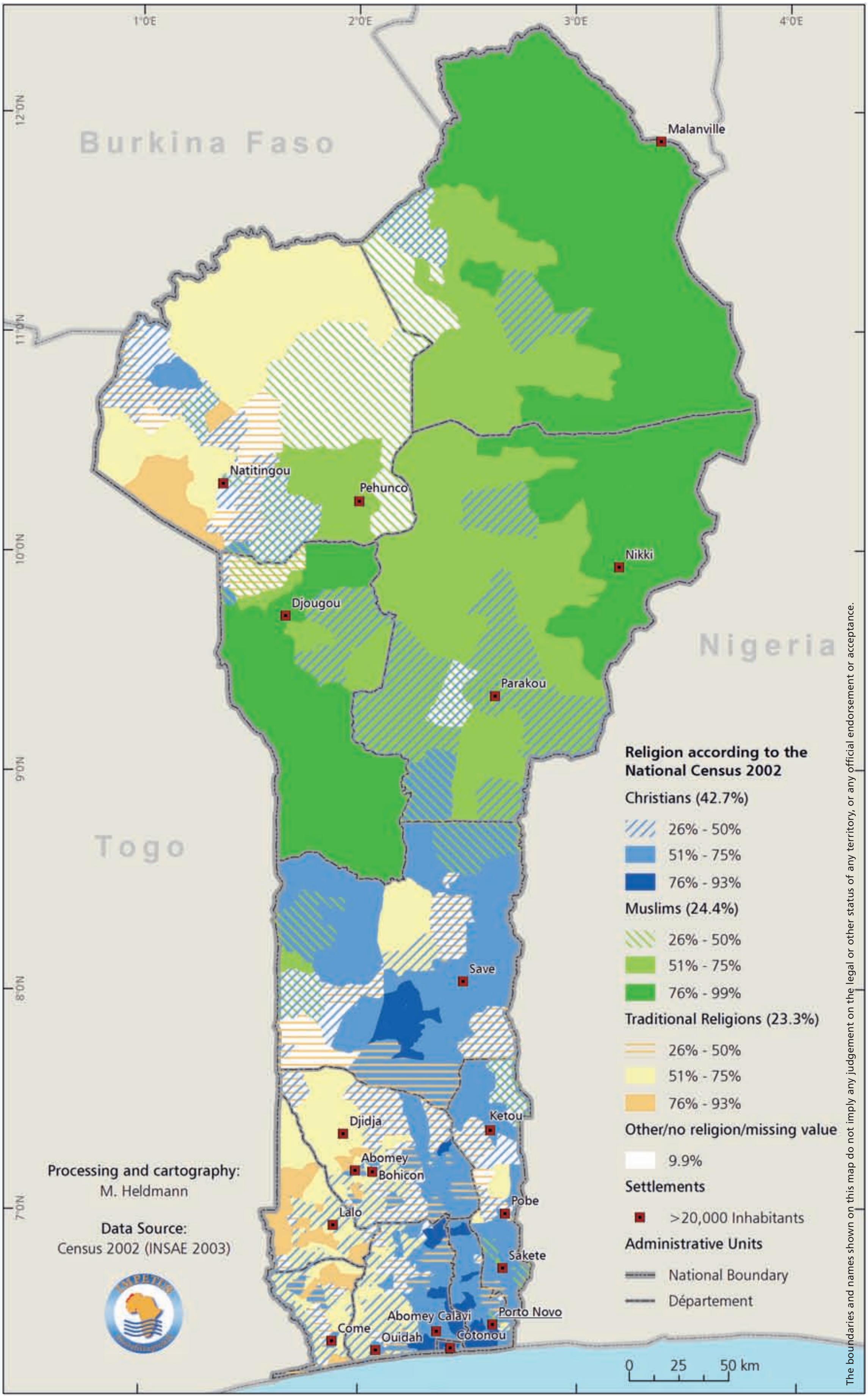

Fig. 2: Map of spatial distribution of religions in Benin

49

Ethnic Groups in Benin

Moritz Heldmann

The national population census in 2002 recorded 59 different ethnic groups in Benin. For the sake of clarity, any cartographic representation has to simplify this confusing mosaic by attributing the particular groups to larger categories using linguistic or historical information. However, even the base data itself is already a simplification, because multiethnic identities were reduced to monoethnic affiliations.

Mapping Ethnic Identities

The mode of data collection has led to a clearly separated classification of mono-ethnic identities. In consideration of the fact that mixed marriages are far from being exceptional and that there is a rising number of multi-ethnic identities, the question, "What ethnic group do you belong to?," as it was posed in the questionnaire of the census in 2002, forced people who live in an ethnically households to opt for only one "official" identity.

Furthermore, it is impossible to map the recorded 59 ethnic groups on a "normally" scaled map. Some of these groups represent only fractions of a local population, while others make up the majority in large areas. It is thus necessary to simplify the confusing mosaic through classification of a great variety of ethnic groups into larger categories for an appropriate cartographic presentation. The National Statistical Office (INSAE) identified 10 categories of "socio-cultural ethnic groups": Adja and related groups (a. r. g.), the Fon a. r. g., the Bariba a. r. g., the Dendi a. r. g., the Yoa-Lokpa a. r. g., the Peulh, the Ottamari, the Yoruba, other ethnic groups, and foreigners (INSAE, 2003). These categories are very large, attributing linguistically very distinct ethnic groups, such as the Yom and the Lokpa, to a common category. To get a more detailed but visually comprehensive view of the spatial distribution of ethnic groups, we divided the initially recorded 59 ethnic groups into 16 wider groups (see Fig. 1).

Spatial Distribution of Ethnic Groups

These 16 ethnic groups are mainly classified according to linguistic features. They are represented as hatched if they reach more than 25 % and in full color if they reach more than 50 % of the population at the level of an arrondissement. In fact, most Beninese speak languages belonging to sub-groups of the Niger-Congo-Family, such as Gur, Kwa, Defoid-Yoroboid, Mande or Senegambian. Only the Dendi and Djerma, living in the extreme North of Benin and around Djougou, belong to the Nilo-Saharan Family.

The Kwa speaking groups mainly live in the South and South-Central Benin, which is historically linked to the kingdoms of Danhome and Porto-Novo.

The Yoroboid groups are subdivided into several groups, such as the Nagot, the Idaca or the Mokole. The latter settle in the North around the city Adjohoun. Most Yoroboid groups, however, live in Central and South East Benin.

The Gur speaking group comprises a multitude of very different ethnic groups, living in Central and North Benin: The Yom and the Lokpa settled between Djougou and Bassila, the Otammari, Gurma and others in the Atacora region. The largest Gur speaking group is the Bariba, in North and North East Benin. Approximately the same territory is inhabited by Fulani herders, who speak a Senegambian language.

The Boko, a Mande speaking group, live in North East Benin, close to the Nigerian border.

As the map impressively shows, Benin has no monolithic ethnic regions but is rather a mosaic of heterogeneous local units. These units are far more complex than what can be shown on the map, which shows only those groups representing more than 25 % of the population in a particular territory. Furthermore, the ethno-linguistic pattern of the country is dynamic and constantly evolving through migration, marriage, and other influences.

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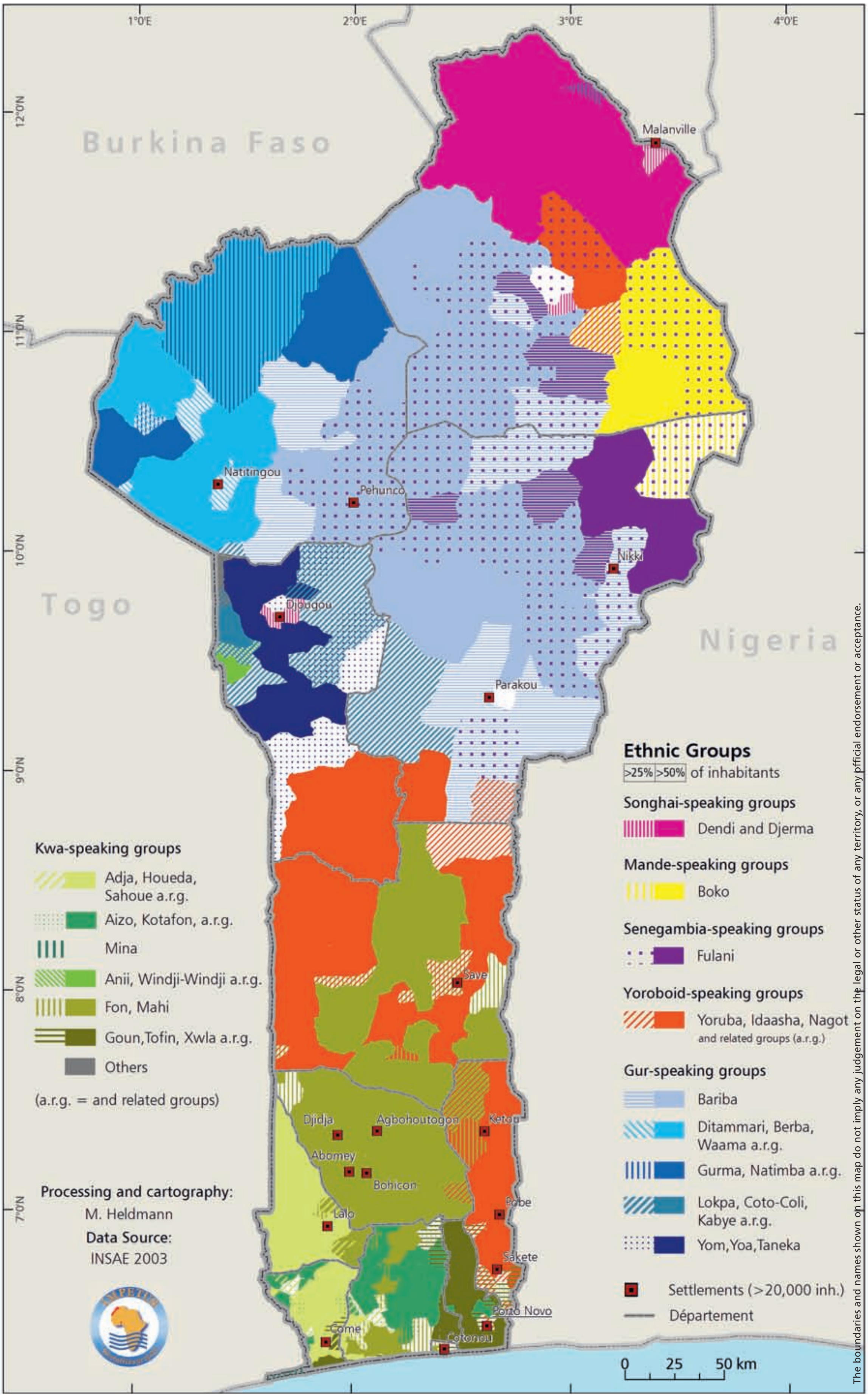

***Fig. 1:** Distribution of ethnic groups in Benin according to the Census 2002*

Illiteracy and School Attendance

Moritz Heldmann and Martin Doevenspeck

Education is a key factor for the economic development of any country. Illiteracy rates and data on school attendance available through census data (INSAE, 2003) illustrate the spatial and gender related inequalities of school attendance and illiteracy in Benin.

Illiteracy

In Benin, more than 50 national languages exist (Gordon, 2005), and many citizens speak at least two or three of them. French is the official language, but as an "imported" European language, it is often not spoken before school. Lessons at school are given in French, even though there also are some alphabetization campaigns in different Beninese languages. Thus, the majority of literate Beninese can write in French rather than in their mother tongue (see Tab. 1).

The mapped rates of illiteracy and school attendance (Fig. 1.) are defined by census data from 2002. Apart from poverty and illnesses, illiteracy is a major factor hindering progress toward sustainable development. Despite some progress in the education sector (in the national school system as well as through alphabetization campaigns for Beninese languages) during the last ten years, Benin is a country where illiteracy is very high. Nearly 59 % of the population can't read and write in French or their vernacular language.

Tab. 1: *Illiteracy in Benin: population aged 6 years or more (INSAE: 2003)*

Population aged 6 years or more	Total	Men	Women
Illiterate	59 %	49 %	69 %
Read and/or write French	33 %	42 %	25 %
Read and/or write a vernacular or other language	4 %	6 %	4 %
ND	3 %	3 %	3 %

Especially among women, illiteracy is high in Benin, reaching 69 percent in comparison to only 49 percent among men. Furthermore, illiteracy rates are much higher in North Benin in comparison to the South of the country.

School attendance

The maps on school attendance highlight the same spatial and gender-related disparities as illiteracy. A 57 percent primary net enrollment rate for girls (UNICEF, 2003) shows that half of the female population of school aged children are denied the right to education.

Gender disparities amount to 16 percent at the primary level (Tab. 2). In addition, the majority of those girls who do enroll drop out of school before the end of the primary cycle.

Tab. 2: *Levels of education: Population aged 3 years or more (INSAE, 2003)*

Level of education	Total	Men	Women
Primary	1,699,516	58 %	42 %
Secondary	639,003	65 %	35 %
University	66,232	77 %	23 %

The gender gap, as related to school enrollment, is, however, slightly decreasing: The ratio of men to women who are currently at school is 58 % to 42 %, in comparison to the ratio of men to women who have attended school, which is 62 % to 38 %.

There are also spatial disparities concerning illiteracy and school attendance. A large gap between the North and the South shown in the maps is an inheritance of education policy under colonial rule, which focused on South Benin.

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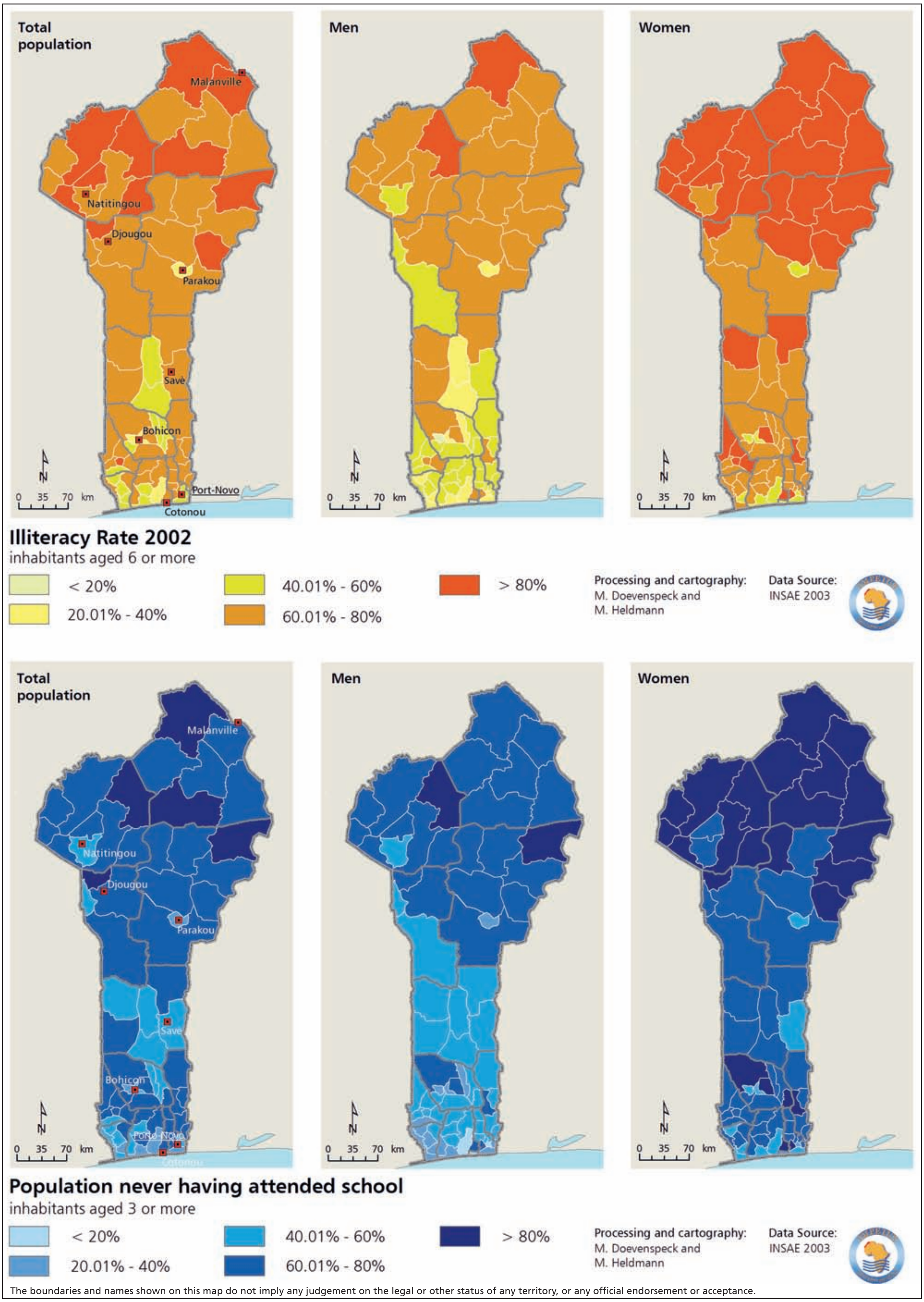

Fig. 1: *Illiteracy and school attendance in Benin*

51

Settlement Dynamics in Central Benin

Martin Doevenspeck and Uwe Singer

Central Benin is marked by migration processes that explain the diversified settlement structure. Historical events, such as the immigration of warlords and Fulani herders and recent processes such as the immigration of farmers from the north-western parts of the country are closely interrelated and have led to a complex multiethnic settlement and population setting.

Wasangari Foundations

The maps (Fig. 1–3) show historical and recent processes of settlement dynamics in central Benin. The oldest settlements visible on the two maps were founded during the period of the Wasangari leadership. These warlords governed the Borgou region and their people until the colonial repression at the end of the 19th century. Their conflicting leadership was characterized amongst other things by the violent appropriation of caravan goods, cattle, slaves (Gando) and agricultural products. That is why many foundation myths of the oldest settlements in the three maps, such as Wari Maro or Tchatchou refer to consequences of this kind of governance, such as escape and the creation of hiding places or succession conflicts between the warlords. In the new settlements, they exert political power, whereas the autochthonous hunters and farmers, such as the Bariba and the Nagot, exert spiritual power and control over natural resources.

Fulani Immigration

The immigration of Fulani from the neighboring regions dates back to the middle of the 18th century. As wageworkers for herding, they first depended both economically and politically on autochthonous people. From the early 19th century onward, French colonial rule lead to the stop of violent appropriation and weakened the dependency of Fulani and Gando on the Bariba and their warlords. This resulted in economic autonomy, which was based mainly on herding and farming and, to a certain extent, resulted in the erection and dispersion of their settlements (Fig. 1).

Recent Settlement Dynamics

The extension of transport infrastructure, especially the building of the railway and the main tracks (Fig. 1), was based on forced labor. The transportation network, together with new market opportunities after the Second World War, led to a

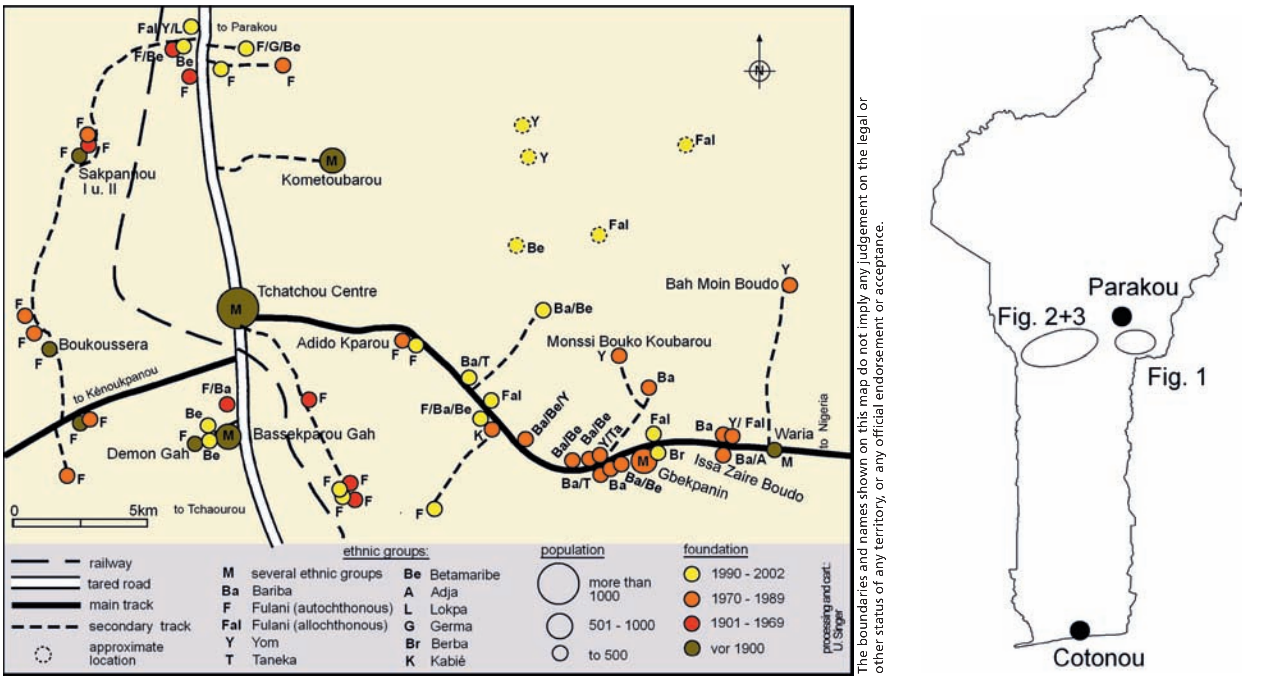

Fig. 1: *Settlement dynamics around Tchatchou*

concentration of settlements along the main tracks and to increased agricultural production.

In the 1960's, various resettlements further contributed to these interlinked processes (Fig. 2). Large parts of the population were forced to leave their villages in the forests, which were difficult for the authorities to control, and create new ones beside the roads.

Since agriculture was mainly based on shifting cultivation, this entailed an expansion of farmland and thus led to a growing distance between the villages and the fields. Seasonal field huts such as Gbékpané (Fig. 1), which means "the hut that became a house" became permanent villages. Apart from the occupation of fertile land, conflicts among and between parent groups also contributed to the further creation and dispersion of settlements.

Fig. 2: The forced resettlements in the region of Bétérou

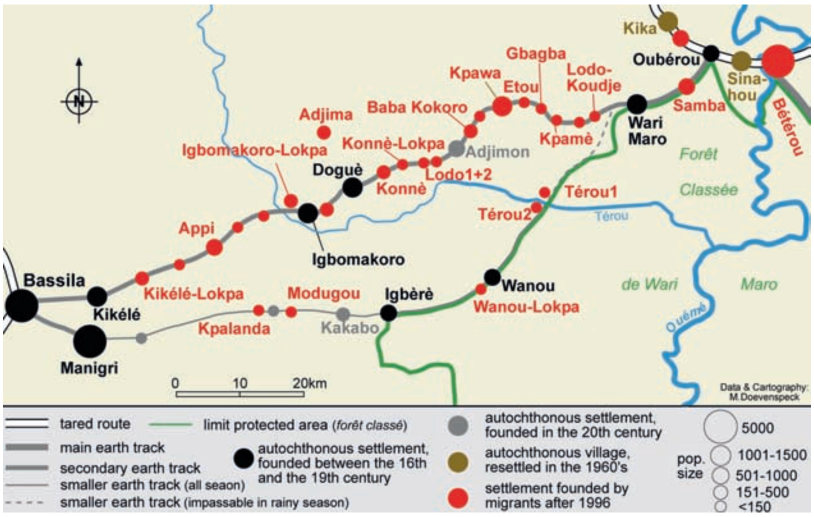

Fig. 3: Old autochthonous and new migrant settlements between Bétérou and Bassila

Since 1970, the settlement dynamic has been accelerated by means of two interrelated processes of immigration. Seasonal wage-workers as well as permanent immigrants from the northwestern parts of Benin and the neighboring countries are attracted by fertile lands and income opportunities. These arose from the state-run cotton market and an increasing demand for food crops, such as yams, on the national markets and in neighboring countries.

In the area between Djougou, Bassila, Tchaourou, and N'Dali, a dynamic agricultural colonization through peasants took place starting in 1970 triggered by settlement programs of the state and Christian churches. The area under investigation between Bétérou in the east and Bassila in the west remained largely untouched by this colonization process until the second half of the 1990s due to the absence of a well-developed transport infrastructure. The expansion of the rural road network in the southern part of the upper Ouémé valley since 1997 offered the opportunity of immigration for peasants and pastoralists. As indicated by Fig 3., the number of settlements founded by migrants since then already exceeds those of old autochthonous villages.

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52

Regional Survey on Livelihood Security

Kerstin Hadjer, Thamar Klein and Uwe Singer

How do people in rural and urban areas ensure their daily livelihood? In order to answer this question, IMPETUS developed an innovative statistically representative survey while pursuing an actor-centered approach. Data were generated by interviewing men and women separately because social and economic management at the household level occur in highly individualized forms. The results provide new perspectives on local risk management in an area of 22,260 km².

An Innovative Approach

Until today, most representative surveys on livelihood security in Benin have been based on the household level as a reference unit (e. g. IFPRI, 2001, MAEP, 2001). This assumption neglects the complex gender relations in Benin as well as their effects on livelihood security. Women and men operate economically at highly individualized levels and with separate budgets. Even if they are living in one household, the accumulation of money and wealth proceeds separately (c. f. Hadjer, 2006 and Klein, 2006). Consequently, an exclusive interrogation of – primarily masculine – household heads does not take into account essential forms of securing livelihood.

In contrast, the present survey is based on an actor-centred approach. This implicates social, economic, and cultural particularities – among them, multi-ethnicity, intra-rural migration, gender differences, individual accumulation of capital, or urban / rural-divides.

Investigation Area and Methodology

The interdisciplinary and statistically representative survey produced data on a variety of aspects concerning daily livelihood security in rural and urban areas. Interviews with 839 participants were carried out in seven districts (*Communes*) of the *Departments* Donga and Borgou, covering about one fifth of Benin's total area (Fig. 1).

The sample was based on the population census of the Beninese National Statistics Office INSAE. Six registration districts (*zones de dénombrement*) were selected by a simple random sample for each of the seven districts. For every one of the 42 *zones de dénombrement*, we received a sample list of ten randomly selected household heads. Additionally, we decided to interview the first wife of each male household head. A challenge in the research process consisted in the multitude of languages in the survey area – 35 different languages were spoken in the sample population. Therefore, male and female interviewers with different linguistic skills were employed in order to cover at least the most frequently eleven spoken languages. The standardized questionnaire was translated, pre-tested, and revised into the eleven most frequently spoken languages.

Focusing on Social Vulnerability

Vulnerability can be defined as the „[...] exposure to contingencies and stress, and difficulty in coping with them. Vulnerability thus has two sides: an external side of risks, shocks, and stress to which an individual or household is subjected, and an internal side that is defenselessness, meaning a lack of means to cope without damaging loss" (Chambers, 1989, p.1).

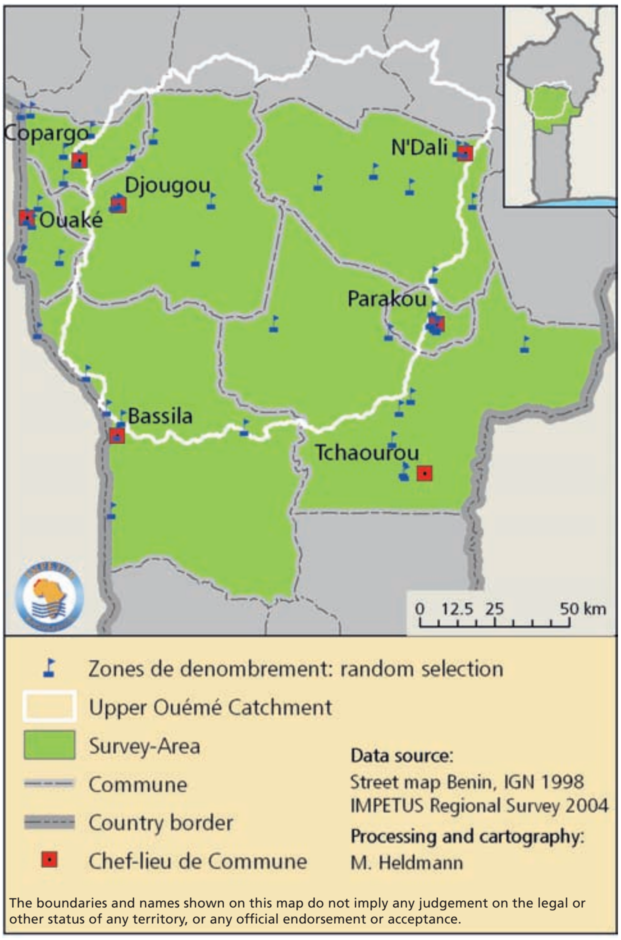

Fig. 1: *Investigation area*

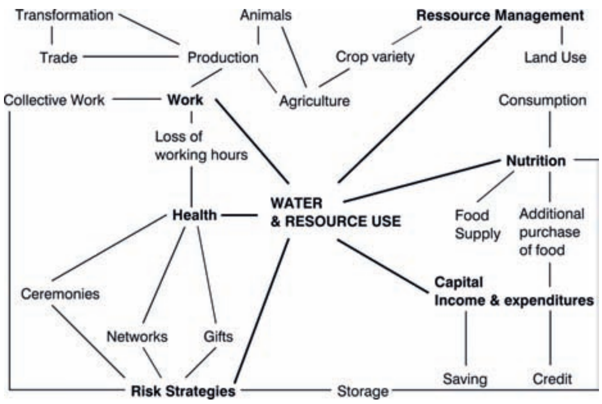

Fig. 2: *Conceptual Framework.*

Especially in the context of decentralization processes, evaluations of vulnerability belong to the most important pillars of advancing sustainable development in the struggle against poverty. A holistic approach is necessary in order to carry out these evaluations. As a result of the insights gained from previous studies carried out by the authors, 77 key variables were determined covering the domains shown in Tab. 1.

Conceptual Framework

The resulting conceptual framework (Fig. 2) of the highly interrelated elements enables diverse, multivariate steps of analysis. In sum, the project provides data on a personal, communal, and departmental levels, which can be scaled up. Furthermore, it provides basic information for local capacity building.

Tab. 1: *Central Domains of Livelihood Security*

Domain	Content (examples)
Potable Water	access, quality, sources, criteria of choice, management of crisis, ..
Work	production, distribution, wage labour, cooperation, ..
Health	waterborne diseases, child mortality, birth rate, ..
Risk Strategies	gift exchange, networks, reciprocity, ceremonies, ..
Ressource Managment	land use, properties, crop variety, conflict management, ..
Nutrition	self production, purchase, degree of satisfaction, kcal/p/day, ..
Capital	Capital income, expenditures, credits, saving strategies, investments, ..

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53

Central Issues of Social and Economic Behaviour

Kerstin Hadjer

Many studies on social and economic acting in central Benin focus on the household level. This approach has been qualified by recent anthropological research, because fundamental economic consequences of gender differences and individuality are neglected. The high degree of socially embedded individualization culminates in secrecy concerning income. Fears of jealousy and occult practices are behind it.

Gender differences

In most cases, women and men earn income primarily seperately in central Benin. Nevertheless, within productive processes, cooperation or commercialization are not excluded. Gender differences are considerably accentuated by the patrifocal social structure: Filiation and descendance proceed by the male lineage (patrilinearity), at marriage women move to their husband (virilocality), and a man can be married to multiple women (polygyny). These pillars of social organization are related to strategies of heritage and residence promoting the gender specific heterogeneity of requirements and intra-household wealth differences.

Distribution of economic activities

Generally, people adopt multiple strategies of livelihood security (polyactivity). In a survey (↗52), we asked 839 people for their three main economic activities over the year. Their distribution is illustrated in Tab. 1. As shown, men dominate agriculture, women trade and proceeeding of raw goods into food (e.g. butter, charcoal; cf. Fig. 1). Especially in rural areas, intra-household responsibilities are clearly distributed between the sexes. For instance, cooking, water fetching, or wood gathering are female domains. Cattle, the shed, or hoe production are well-defined male domains.

Individuality and wealth differences

Numerous studies and (inter)national surveys limit their interrogation to (almost male) household chiefs, assuming that they are well informed about the economic activities of the other household members (e.g. IFPRI studies, 2001; MAEP, 2001; INSAE, 2004).

In contrast, Hadjer (2006) furnishes results unambiguously disproving the assumption of pooling at the intra-household level. She accentuate the strategy of secrecy as well as the resulting division of capital. For household members, the individual separation of (knowledge about) money and wealth involves a different access to resources (e. g. land) and to different sorts of capital (e. g. money).

Tab. 1: *Economic activities (n=1139) by sex (790), Regional Survey, 2004*

Economic activities	Men	Women	Total
Agriculture & Forestry			
cultivation	256	122	*378*
horticulture	105	29	*134*
livestock breeding	29	12	*41*
forestry	6	0	*6*
total	*396*	*163*	*559*
Craft & Industry			
small-scale processing of agricultural products and commercialization	0	101	*101*
industry	3	0	*3*
craft	62	25	*87*
total	*65*	*126*	*191*
Services			
trade	30	283	*313*
education	7	4	*11*
health	18	2	*20*
other	41	3	44
total	*96*	*292*	388
Total	*557*	*581*	*1138*

At first glance, the daily life inside of residence units seems to function by an economy of solidarity. But in fact, we can observe on a household level a wide range of individualized acquisitive strategies and modes of accumulation, all culminating in marked differences of income. Economic deals occur less often between households, but rather between individuals.

Thus, men buy, for example, sorghum from their wives and bargain for the best price. A woman obtains a credit from her husband and a few months later he asks her to pay interest. A married couple visits a wedding party together, but they bring along individual gifts of different value according to their personal relationship with the bride or bride

Fig. 1: *Typical female and male domains of work*

groom. In the course of the wedding party, the couple practices networking independently from each other.

All told, we identify market-oriented structures on the intra-household level. They are associated with pronounced gender differences. However, detailed data on budgets of couples in West Africa were unavailable before the "IMPETUS daily study on income and expenditures of both sexes in the course of one year" (Hadjer, 2006). This study detects important differences in the material and monetary distribution of wealth at the intra-household level.

Moreover, the course of the study delivers a vivid example for the omnipresence of secrecy: During its realization, income and expenditures of women and men were recorded separately in one notebook per person. Indeed, some participants refused to keep their notebook at home fearing that their partners could read it.

As shown in Fig. 2, the balance sheet of income proves that women's incomes are more stable, but at a lower level. Curves of individual consumption and expenditures reveal an analogous progression.

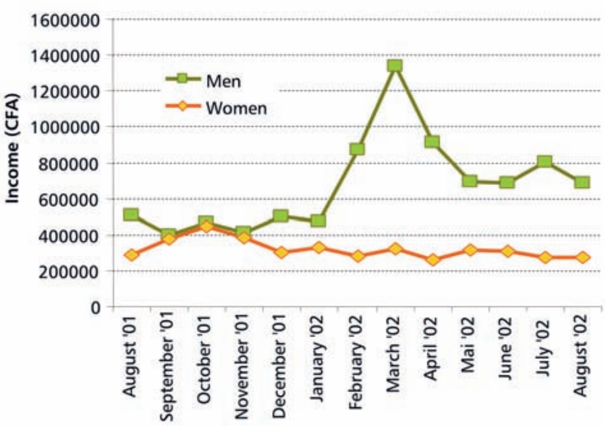

Fig. 2: *Income/Month (n=16) by sex in the year 2001/2002, Bougou*

Local risk strategies

Where income is irregular and the dependence on external factors like rain (in case if rain fed agriculture) is very high, precautions have to be taken for times of shortage. The most salient strategy is maintained equally in urban and rural areas: highly gendered networks. For example, an active gift exchange takes place all year long. In time of crisis, 75 % of gifts turn first to relatives (n = 839). Women exchange higher amounts of gifts in shorter time intervals and with a higher rate of reciprocity than do men. They save more frequently and regularly than men. While men often possess bank accounts, women's domains are popular saving systems (*tontines*).

Outlook on magic impacts

In sum, gender differences and the high degree of individuality are central issues of social and economic behavior. The secrecy concerning (knowledge about) money and wealth is based upon efforts to avoid envy and jealousy (Hadjer, 2006).

Moreover, envy and jealousy can lead to the application of occult practices. Thus, secrecy concerning money serves also as protection against occult attacks, which appear at all levels of human behavior. Their ignorance in survey design and interpretation of the results leads to falsified conclusions (↗54; in detail: Hadjer, 2006).

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Occultism and its Impacts on Economic Behaviour

Kerstin Hadjer

Beninese politicians drive to Ghana, where they purchase expensive occult supports for the next elections. Passengers invest their last monthly salary in the fabrication of gris-gris in order to be protected in case of an accident. Magic or occult practices occur at all levels of society. They can be executed to thwart the economic prosperity of a brother or a concubine. They may serve to be healthy or wealthy and provide protection or social cohesion. All in all, magic costs money.

A powerful, secret universe

In Benin, occult practices are omnipresent. At the same time, science rarely pays attention to its strong impacts on social and economic activities. However, throughout the whole country we meet a complex co-existence and many hybrid synergy effects between religions like Vodoun, Islam, or Christianity with ancestor worship, beliefs in genies, witchcraft and other occult practices (↗48).

Financial investments in the protection against the ill as well as expenditures for positive magical power are realized at all levels of society. Similar to medical physicians, mediating seers or healers are often high-grade specialists, but they disclose secret knowledge. In general, the occult domain is interspersed with secrecy and allocates secret practices to promote jealousy and envy.

Nevertheless, the approach of participant observation and extensive interviews in the IMPETUS research area detected a wide range of occult techniques, among them were evocation, invocation, trance, ritual magic, ceremonial magic, and oracles (Fig. 1). Destructive witchcraft and dangerous secret societies constitute only a part of the occult universe, which is concurrently inhabited by cohesive powers (e. g. genies, Fig. 2) effecting healing, enchantment, sage divinations, or collective and cohesive sacrifices.

Occult practices as risk strategies

In central Benin, occult practices notably may concern protection, fortune, damage, bedevilment, or possessions. The lower the price, the more often it has to be "refreshed."

Investments in the occult are a very common kind of risk-coping strategy. For example, a project assistant did not have the courage to continue the construction of his house without magical protection. He explained this by his fear of envy, which may result in destructive sorcery. A taxi-driver doesn't dare work without magical protection. A village collectively evokes genies in order to get rain or protection. Occultism proves to be an important component of livelihood strategies and daily social practice.

Financial burden

Occult ceremonies and products require capital. The costs involved may exceed the yearly mean income of a market-woman. Occult practices may become institutionalized, such as the transmission of sick people from hospital to healers and specialized

Fig. 1: *Oracle and invocation of genies to identify problems of a client*

Fig. 2: *Perfume bottles: Part of a cult side and domicile of genies*

Fig. 3: Protection jewellery (21 €)

Fig. 4: Cult side (close to Wagga)

seers. They earn money and work in a profit-maximizing way. In contrast, so-called witches execute spiritual cannibalism by nourishing themselves on the sacrifices of human souls.

Personal relationships, the degree of professionalism, and the power of seers or healers play major roles in price levels. It is impossible to quote a generalized, fixed price for a special product: The richer and more powerful the client, the more elaborate and costly his/her protection or healing and, thus, the more expensive the specialist.

Expenditures for prosperity and fortune

It is difficult to distinguish between occult practices establishing protection and those causing damage, since the fortune of one person can lead to the damage of another. Moreover, in languages as Yom, the term *tiu* is used similarly as an umbrella term for a magical and biomedical remedy. Ritualized kinds of mediums are, for example, powder, soaps, or beverages. Recorded prices go up from 15 to 457 €. A high school graduate paid 23 € for a powder to pass an exam. This amount approximates the monthly salary of an elementary school teacher.

A lot of people wear a kind of *gris-gris* (Yom: *wurun*) under their clothes, which is like magic jewellery (e.g. Fig. 3). They are convinced that this will protect their homesteads, fields, market goods, as well as crops against evil witchcraft, thieves, or occult practices.

Possessions, genies and witchcraft

Genies (*djin*) are able to bring about good fortune, convalescence, and prosperity. They mostly inhabit natural fetishes, as shown in Fig. 4. According to the fetish guard, people arrive from diverse countries in order to receive solutions for problems like female sterility. Women pay a second financial contribution after successful childbirth. But genies can also be vexed or dangerous. The combat against possession through genies includes different forms of therapy. In most cases, the treatment lasts several months. In recorded cases, the concerned families paid between 33 € and 280 €, the costs for travel not included.

Moreover, the fear of being under a witch's spell is often accompanied by a more unspecific fear of damage from occult practices. In local French, both phenomena are misleadingly subsumed by the term *sorcellerie* (witchcraft).

Popular products for damaging others are, for example, (partly lethal) poisons. A powerful female seer set a minimum price of about 46 € for dangerous poisons. Witches (in Yom: *soowa*) often act through mediums like owls, dogs, spiders or serpents. Popular preventives and alexipharmic agents are powders or *gris-gris*. They are available at all price ranges.

Certainly, this short introduction leaves a lot of questions on background and details open. But one important conclusion can be drawn: occult practices have a strong impact on daily social and economic action and intervene delicately in the financial budgets of the Beninese population.

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55

Land Property Rights in the HVO

Moritz Heldmann, Kerstin Hadjer and Valens Mulindabigwi

Private land ownership in the sense of accumulable property was ignored in Benin before contact with Europeans. Land is rather seen as Means for Survival for a kin-group of people comprising the ancestors, the living and the unborn members, and represents much more than a production factor. Today, changing customary land rights are confronted with imported capitalist property concepts.

Customary Property Rights

Collective ownership in Benin is based on the principle of the "first comer," meaning that the person who clears a certain area first and makes an agreement with the local earth spirits can claim its use for himself and his family (Degla, 1998). His descendants, as lineage heads, inherit the function of *Earth priest* and – at least theoretically – the power to control, distribute and withdraw the use rights within the group and beyond. Today, nearly all the available land in Benin claimed by the descendents of a "first comer" even if it might have been fallow land for a long time.

The longer the first clearance dates back in time and the less socially stratified a local society is, the more it is likely that the effective property rights get dispersed among broader and distantly related kinship groups. This is also the case in parts of the HVO, where some earth priests only conserved their spiritual role as mediators between the earth spirits and the population but lost effective control over the land.

The power of land control can thus be split up among different actors ranging from symbolic to effective but never comprises the right of monetary alienation.

Today, the customary land tenure concept is confronted with the imported capitalist property concept and faces demographic pressure and increasing land scarcity. The commercial alienation of land – regardless of any social or spiritual functions – is the key element of the capitalist property idea and the basis for credits, which is often seen as a core element of rural development.

Legal Pluralism

The national land legislation based on the colonial land law did not take into account the customary land tenure until recent reforms. The current land tenure situation is thus characterized by land rights insecurity and a legal pluralism on several levels. First, between the national law and the customary laws, and second, within the customary laws themselves, which are constantly changing under the described conditions. Indeed, in general, insecure property and use rights hinder sustainable investment and complicate access to credit needed for agricultural investment (Neef, 1999).

Legal uncertainty is above all a major problem in South Benin where land resources are scarce and population density is high. At present, several reforms aim to ameliorate the land tenure situation in Benin by means of harmonization and documentation of the land tenure systems, and by delegation of responsibilities. The new land law (*Code Foncier*) is the legal basis for a harmonization of customary and official land rights. The new simplified rural cadastres (*Plan Foncier Rural*) aim to increase legal certainty through a documentation of customary property or use rights. The implementation of these cadastres is delegated to the decentralized *Communes* aiming to reduce the costs of acquiring land titles.

Property claims in the Upper Ouémé region

IMPETUS research confirms that the documentation on land property is lacking for the Upper Ouémé catchment. Only 5 % of the survey population (Parakou excluded) with access to land (n = 541) had documents proving their property rights.

The sale and the purchase of land are still rare. Less than 2 % of the survey population (n = 839) ever sold land. However, 5 % of the population with access to land declared having purchased it. The purchase rate is highest in Copargo and lowest in Tchaourou, where population density is lower and land less scarce (Fig. 1).

Access to land in the Upper Ouémé region is thus still dominated by customary land tenure systems. Sixty percent of the population with land access inherited their rights, and 34 % declared to have only use rights compared to only 5 % who said that they purchased the land.

A customary indicator for land property claims are tree plantations. As tree planting is generally pro hibited to non-owners, trees are regarded as prop-

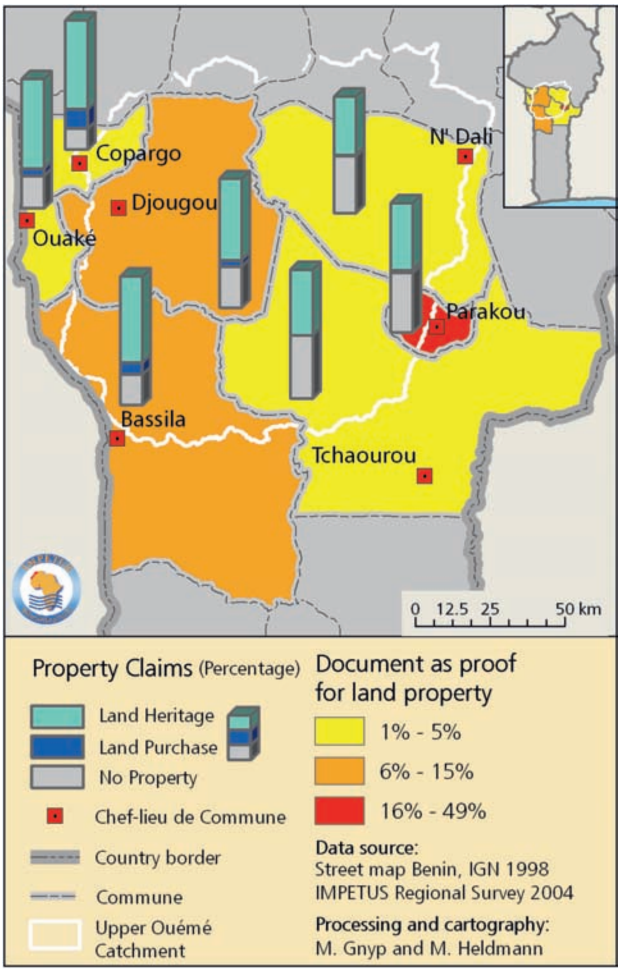

Fig. 1: *Property Claims and Documents on Land Property (n = 541)*

erty markers. However, only 60 % of the owners who inherited land declared to have trees on it. In Tchaourou, their number rises to 84 %, due to the fact that cashew plantations are the major cash crop in this area. Property claims are thus not generally emphasized through tree planting. Even non-owners are sometimes allowed to plant trees.

Uneven distribution of land property among women and men

An accurate documentation of property rights is impossible because of legal pluralism, legal uncertainty, and the context of change in land tenure practices. However, a significant trend can be detected: Women are particularly deprived of land property rights. In customary land tenure, women can generally not inherit land but have to borrow a small piece of land from their husband. According to the regional survey, only 10 % of the inherited land is claimed by women (Tab. 1).

Tab. 1: *Distribution of inherited land among women and men (total percentage)*

Do you have inherited land?	Men	Women	Total
Yes	50 %	10 %	60 %
No	20 %	20 %	40 %
Total	70 %	30 %	100 %

Source: Impetus Regional Survey, n = 541

Tab. 2: *Size of inherited land among women and men (percentage in columns)*

Size of inherited land	Men (%)	Women (%)	Total (%)
until 1 ha	3 %	40 %	9 %
1.01 ha – 5.00 ha	28 %	53 %	32 %
5.01 ha – 10.00 ha	26 %	4 %	22 %
10.01 ha – 20.00 ha	21 %	3 %	18 %
> 20 ha	21 %	0 %	18 %
Total	100 %	100 %	100 %

Source: Impetus Regional Survey, n = 319

The unequal distribution of land property among women and men is also evident with regard to the area sizes. The 10 % minority of women having inherited land claims only small lots below 5 or even 1 hectare (Tab. 2).

In an environment of change of customary land tenure and increasing individualization of land rights, women are largely deprived of land property. With regard to this, it is clear that women in rural areas have different livelihood strategies than men, and are less active in cropping (Hadjer, 2006).

Today, customary land tenure is still predominant in the Upper Ouémé region. But population growth, land scarcity, and agricultural investment from urban elites will certainly contribute to further change in land tenure practices. Land policy needs to manage this process.

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Land Use Rights: Migrants and Foreign Cattle Herders

Valens Mulindabigwi, Moritz Heldmann and Kerstin Hadjer

Land security in the context of the land right implies an assured access and use of land as well the right for farmers to enjoy their products. The results of a statistical representative regional survey (↗54) in 2004 with 839 women and men show, that immigrants in the Upper Ouémé Catchment come across restrictions that completely prohibit them from carrying out certain agro-pastoral activities. This compromises their livelihood security and the sustainable use of natural resources.

Restrictions in land use right

In the Upper Ouémé catchment, particularly in the *Communes* of Bassila and Tchaourou, migrants still obtain land, where they settle and work in agricultural activities (Doevenspeck, 2004; Mulindabigwi, 2006). The land acquisition is, however, accompanied by restrictions prohibiting the immigrant to carry out certain agro-pastoral activities (Mulindabigwi, 2006). These activities can be divided into three categories: (1) use of natural resources, (2) plantation of perennial crops and afforestation, (3) livestock.

Exploitation of natural ressources

Concerning the exploitation of natural resources, the agricultural migrants and livestock owners (especially Fulani, e. g. in transhumance) generally have neither the right to pick néré (*Parkia biglobosa*) and karité (*Vitellaria paradoxa*), nor to exploit wood (Tab. 1, Fig. 1). However, the karité constitutes an important tree in the context of livelihood security, especially for the women who produce and commer- cialize shea butter. The exploitation of forest is strictly prohibited for immigrants in all communes except in Ouakè and Parakou, where no more natural forests offering wood for exploitation are left. Fishing in sacred ponds (marigots) is another strictly prohibited activity. In general, fishing in ordinary ponds, the exploitation of land with water points and free access to water points for fishing are less prohibited. However, in the communes of N'Dali and Tchaourou, it is imperiously difficult for the immigrants to implement activities around the natural water resources or to appropriate and use the inland valleys (Tab. 1, Fig. 1).

Perennial Cultures and Afforestation

The prohibition of the perennial plantations concerns the plantations of cashew or mango trees, citrus fruits, teak, etc. The interdiction of agroforestry and perennial plantations places the immigrants in a precarious nutritional and economic situation and compromises the efforts to protect and conserve the natural resources.

Livestock

Taking in consideration the importance of the existing conflicts between the livestock owners and the farmers, the interdiction of cattle livestock towards immigrants is paradoxically mentioned in only 4,6 % of the cases. As long as the cattle does not destroy cultivated land the herdsmen are mostly free to move with their animals on the land of autochtone land owners. In times of growing land colonization, this right however becomes theoretical. Furthermore, neither the livestock owners, nor the farmers respect corridors of transhumance and the use conditions of dams, which consequently involve the destruction of the cultures and afterwards lead to conflicts between the two communities.

Conclusion

Natural resource use restrictions imposed on immigrants constitute an important factor of socio-economic exclusion in rural Benin. Several factors may explain the evolution of exclusion: a) the absence of secure formal institutions governing the exchange of use rights for resources, b) uncertainty about the immediate readiness of immigrants to comply with the sometimes complicated rules governing resource use within the autochtone communities, and c) preservation of autochtone investments into communal natural assets (e. g. planting trees, preserving ponds).

However, two other factors alleviate the negative impact of exclusion on immigrants: a) exclusion does not last forever; it is phased out after a couple of years, depending on the degree to which immigrants have integrated into local communities and have internalized their rules, and b) the emergence of formal institutions and markets for resources (e. g. land titles and the monetization of land transactions) provide increased certainty to autochtonous resource owners that immigrants can be forced to play by the rules.

Although certain interdictions (exploitation of wood, fishing in the pond, loan of land with water

***Tab. 1:** Interdicted activities to agricultural migrants and livestock owners (cases in %)*

Commune	Bassila	Copargo	Djougou	N'Dali	Ouaké	Parakou	Tchaourou	Upper Ouémé
Gathering karité	64.0	47.6	61.4	78.0	70.9	63.1	71.2	65.3
Gathering shea tree	21.8	8.7	11.6	63.6	11.7	51.2	67.2	32.8
Wood exploitation	60.9	76.8	68.8	87.0	42.3	54.7	82.7	68.1
Agro-forestry	67.3	98.2	89.3	92.5	58.7	83.3	72.5	80.7
Cashew plantation	64.3	30.2	42.1	85.2	67.9	83.5	67.6	62.2
Mango trees plantation	60.0	31.3	40.9	85.2	67.9	83.7	67.0	61.5
Teak plantation	70.5	39.3	54.1	86.0	75.0	87.8	68.5	67.9
Cattle livestock	6.1	—	4.5	0.9	13.0	3.5	3.7	4.6
Fishing in sacred ponds	78.2	96.6	92.0	96.3	73.7	90.7	94.0	89.3
Fishing in ordinary ponds	22.7	3.4	4.4	45.5	21.1	12.1	68.7	24.8
Use of inland valleys	30.6	7.9	13.9	75.2	31.5	30.2	49.0	33.9
Land with water resources	18.0	—	9.8	84.2	8.8	19.5	48.5	31.1

Source: *IMPETUS Regional survey 2004 (n = 839)*

points, free access to the fishing water points) are motivated by socio-cultural and economic interests rather than environmental considerations, they constitute an important framework to protect inventories of, and investments into natural resources. On the other hand, they increase the uncertainty of use rights for immigrants and, thus, their readiness to invest into natural assets and resource preservation. Moreover, in their traditional form, the interdictions are likely to nourish conflicts along ethnic lines when pressure on resources through immigration will further increase within the next decades. An equitable and sustainable execution of land law in Benin, particularly from the communes, could contribute to ensure the livelihood security of the population and the protection of natural resources.

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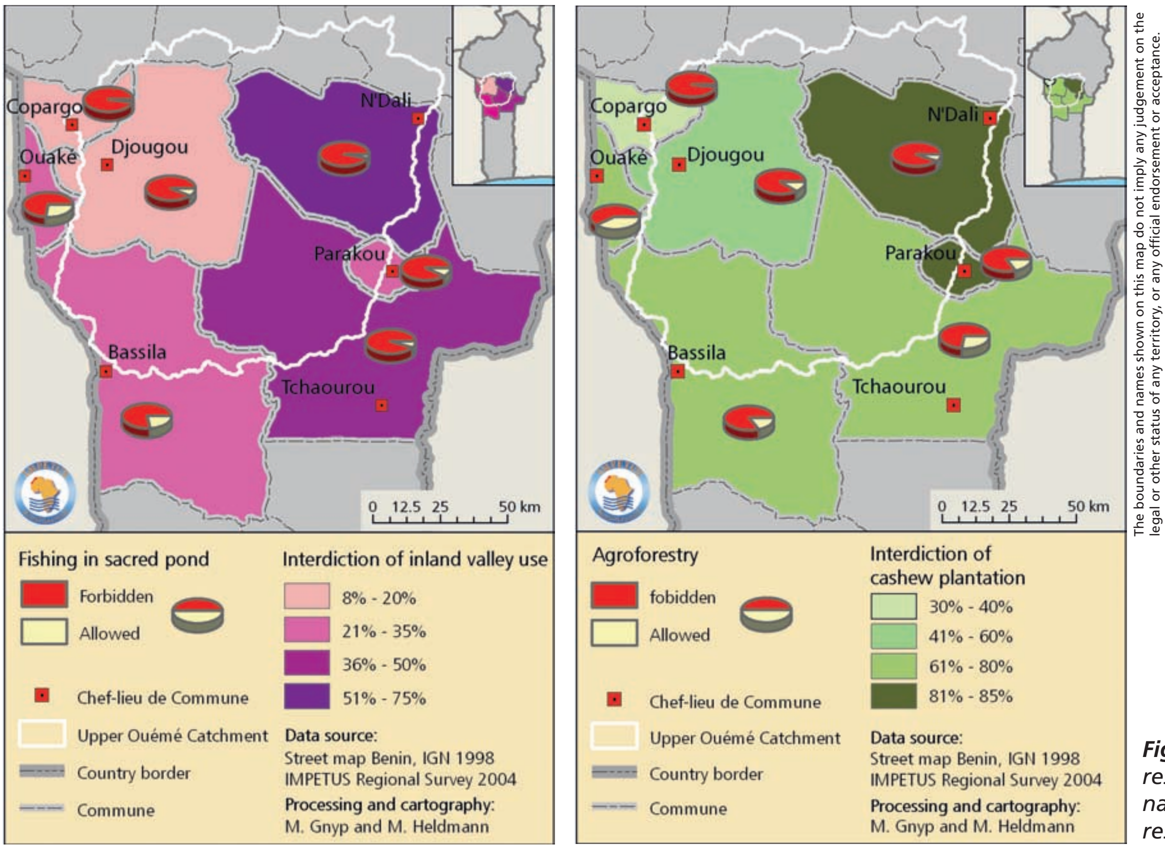

***Fig. 1:** Use restrictions of natural resources*

57

Livestock Husbandry in Benin and Resource Use

Ina Gruber

Livestock management in Benin is characterized by extensive production methods and multi-purpose use of productive livestock. The extensive production mode is based on free access to natural resources. Due to the high population growth, these resources become scarce, putting the current production system under pressure.

Methodology

Two formalized surveys were carried out in 2005 in order to identify future trends in the livestock sector. For the first survey, 34 local experts were consulted. For the second survey, 75 local animal keepers in three different regions were interviewed (Gogounou, Tchaourou, Ouidah). Some of the results of the surveys, which reveal the problems, challenges, and possible developments of the livestock sector, are shown here.

Current livestock management

Within the field of agriculture, livestock management is a separate production system with loose connections to cultivation. Production is extensive with low input of labor and capital. The extensive production mode heavily relies on the access to natural resources (waters, savannah, and forest). The seasonal migration of ruminants following the availability of water and pasture on non-cultivated land is called transhumance. Generally, productivity (measured in terms of meat production per animal) is low, sometimes even lower than the Sub-Saharan average. The reasons for keeping animals are: own consumption, cash/revenue generation, draught power, manure, capital formation, and use at religious festivities and ceremonies.

Production takes place predominantly in the North where pasture is still largely available, while consumption is concentrated in urban centers of the South. The necessary north-south transportation of products is mainly carried out by transporting live animals, as cooled containers are still too expensive.

Challenges for livestock producers

The current production is confronted with several challenges and problems (see Tab. 1). Many of these problems have their roots in the weak property rights of pastoralists and, thus, increasingly insecure access to natural resources. Moreover, the state of the infrastructure (e.g. streets or existence and access to markets) and the organizational status of the livestock keepers are important.

These problems are aggravated by external driving forces. Climate change and the expansion of cropping areas accompanied by a decreasing share of rotational fallow are likely to reduce the availability of pasture. Furthermore, increasing income will lead to a higher demand for meat and milk products.

Possible development

The traditional reaction to increasing demand is to increase the number of animals. This traditional response will not be sustainable when pasture becomes ever scarcer, undermining the resource base of extensive production. Nevertheless, Fig. 1 reveals that the majority of interviewed experts still assume growth rates of livestock, which are equal to or greater than population growth.

The most unambiguous position was given for chickens. The majority of the experts assume that the chicken stock will grow faster than the total population. This disproportionate increase is also projected by half of the experts for the pig stock and small ruminants. For cattle, expectations are much

Tab. 1*: Difficulties in livestock management according to animal keepers and experts*

	Animal keepers in % (n=169)	Experts in % (n=129)
Access to Forage	33.9	25.6
Prevalence of Diseases	24.0	14.7
Access to Water	19.3	10.9
Conflicts over resources	7.0	1.6
Thefts of animals	5.3	—
Marketing of products	—	10.9
Extensive production	—	8.5
Missing consulting/ research	—	7.8
Missing knowledge of animal keepers	—	6.2
Other aspects	10.5	13.8

Source: adapted from Gruber, Kloos, Schopp (forthcoming)

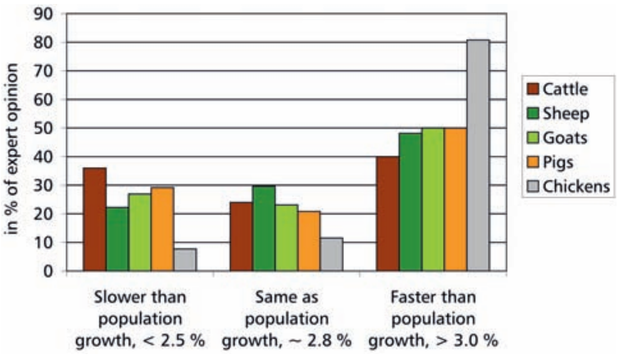

***Fig. 1**: Assumed animal stock growth until 2025*

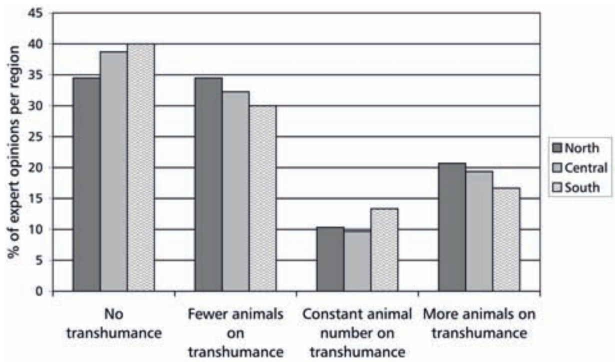

***Fig. 2:** Development of transhumance until 2025*

more uncertain because the production mode would have to change.

Other possible reactions to the changing environment might be a reduction of herd sizes, migration to marginal regions where resources are still available, a shift in the composition of livestock species, the intensification of production, or improved cooperation between livestock and crop producers.

Transhumance in particular will lose its resource base if non-cultivated land becomes scarce due to a continuous expansion of agricultural area. In Fig. 2, the assumptions of the experts with respect to the development of the (great) transhumance are shown. The experts' views tend unambiguously towards a reduction of the number of animals on transhumance.

Most likely a mix of different strategies dealing with increasing demand and the lower availability of natural resources will emerge over the next several decades.

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Level and Formation of Farmland Prices in Benin

Arnim Kuhn, Mousseratou Saliou and Ina Gruber

Regional farm price levels contribute significantly to the pace of the transformation of forest and bush land into cropland. With land resources sufficiently available, this process is largely driven by the growth of the rural population in need for land to grow staple crops. When land is becoming scarcer due to increasing population density, higher land prices tend to curb farm land expansion.

Introduction

Land and labor are still the two most important production resources in Benin's agricultural sector. While the price for farm labor is expressed by the daily wage paid to farm workers, the costs of using land (opportunity costs of land) are reflected in the levels of monetary and non-monetary costs of renting land. The more costly these basic factors of production become in the course of both population growth and economic development, the more rapidly they will be replaced by technology (advanced varieties, fertilizer use) and capital use (machinery) in crop production. Thus, these adaptation processes tend to work against a complete exhaustion of potential cropland resources. The higher the observed regional land rents, the less likely it is that agricultural land use will increase there in the future.

Data collection

In order to collect data on land use on the commune level in Benin, a telephone survey was carried out among farm experts, who were primarily employed at local farm advisory centers (CeRPA). Customary land tenure prices were asked for two categories of farmland: land in rural regions and in sub-urban regions around cities. Moreover, both land tenure and land sales prices were requested. The average relation between tenure and sales price is a proxy for the long-term discount or interest rate of the participating parties in a land transaction. If an expert was not aware of regional land tenure prices, they were derived by multiplying regional land sales prices with the average discount rate.

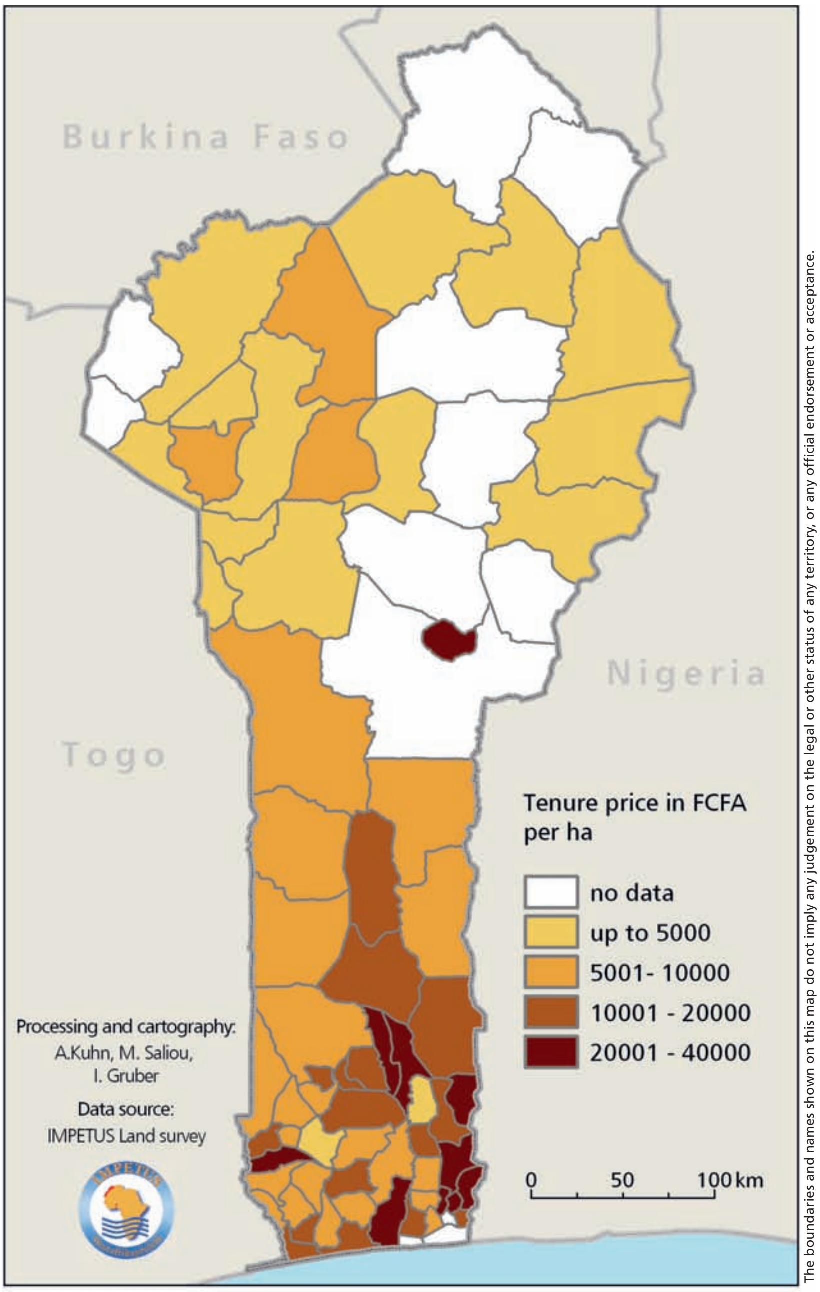

Fig.1: *Regional land tenure price level in Benin (Expert survey, 2007).*

The reported typical land tenure prices range from 3,000 FCFA (Commune Ouinhi) to 40,000 FCFA (Commune Abomey-Calavi) per ha. The map reveals a clear South-North gradient, which indicates that land prices increase with population density and the decreasing availability of land resources.

For some areas in the northern part of the country, no data were available, often due to the fact that land tenure and sales are not yet practiced in these areas.

Analytical approach

Land tenure prices are an indicator of the regional scarcity of cropland. Their formation is determined by factors such as potential crop yield levels, the costs of transforming forest or bush into cropland, the local population's density and growth, or the remoteness of the area in question. The statistical investigation of land tenure prices and their determining factors were carried out at the Commune level. The results may be used to produce regional land price projections.

Results

Table 1 contains a correlation matrix of land tenure prices and population density, the marginality index, and the cropland share in total commune area (the latter three as determining factors). Explanatory variables are also correlated among themselves, which has to be taken into consideration.

The two scatter plots show the relation of tenure prices to the natural marginality of land (see also Röhrig and Menz, 2005) and land use intensity. Moreover, higher population density is likely to reduce cropland availability, as land will also be needed for construction or roads.

A high regional marginality index means that average cropland is of low quality in this region, leading to lower prices (see Fig. 2). Nevertheless, the relation is not too close because in densely populated areas, the quality of soil becomes less relevant for its price, while other land use options gain in importance.

Finally, land prices increase with the share of cropland in total available area, as this directly represents land scarcity (see Fig. 3). Again, however, in densely populated areas, the factors related to agricultural land use lose importance.

Tab. 1: Correlation matrix

	Cropland price	Population density	Agricultural marginality
Population density	0.524(**)		
Agricultural marginality	-0.448(**)	-0.405(**)	
Cropland share in total area	0.517(**)	0.625(**)	-0.414(**)

** Correlation significant at the 1%-level

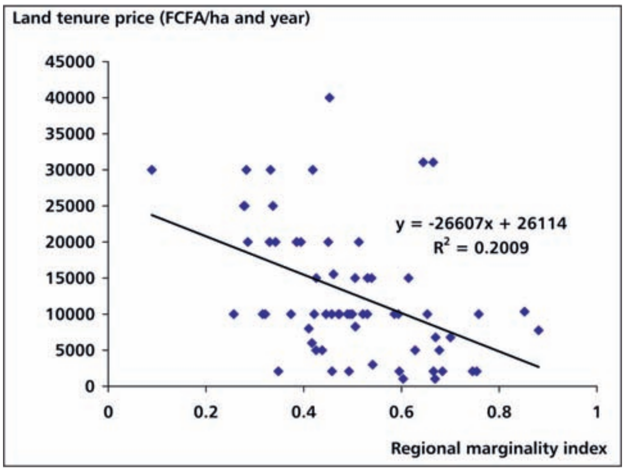

Fig. 2: Agricultural marginality and land prices

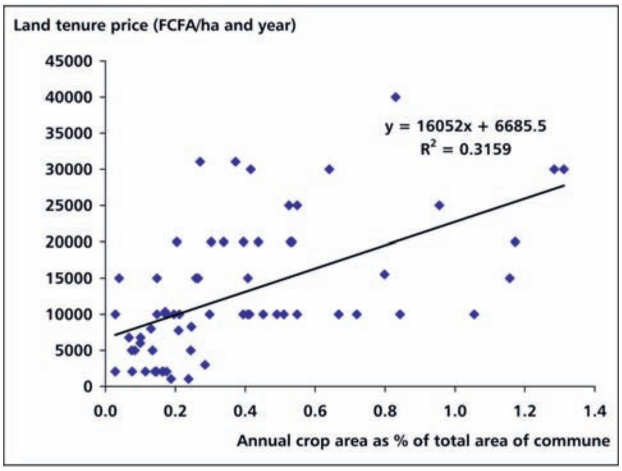

Fig. 3: Regional crop land use and land prices

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Abbreviations

A1B	A climate change scenario based on SRES, defined by th IPCC
AMMA	African Monsoon Multidisciplinary Analyses
ANB	African News Bulletin
B1	A climate change scenario based on SRES, defined by th IPCC
CATCH	Couplage de l'Atmosphère Tropicale et du Cycle Hydrologique
CFA	Communauté Financière d'Afrique
CILSS	Comité Permanent Inter Etats de lutte contre la Sécheresse dans le Sahel
CLINO	Climatological Normals
CLUE-S	Conversion of Land Use and its Effects at Small regional extend
COTEB	Complexe Textile du Bénin
CPCS	Commission de Pédologie et Cartographie des Sols
CeRPA	Centre Régional pour la Promotion de l'Agriculture
DEM	Digital Elevation Model
DGEau	Direction Générale de l'Eau
DH	Direction de l'Hydrolique
DMN	Direction Météorologique Nationale
ECHAM	Atmospheric general circulation model
ECHAM5	5th generation of the ECHAM general circulation model
EIU	The Economist Intelligence Unit
FAO	Food and Agriculture Organization of the United Nations
FCFA	Franc de la Communitée Financiaire Africaine
FOOT3DK	Flow Over Orographically structured Terrain - 3 Dimensional Köln
GCM	General Circulation Model
GDP	Gross Domestic Product
GHCN	Global Historical Climatology Network
GIMMS	Global Inventory Monitoring and Modelling Studies
GIS	Geographic Information System
GLCC	Global Land Cover Change
GPS	Global Positioning System
GTZ	Deutsche Gesellschaft für Technische Zusammenarbeit
HELVETAS	Swiss Association for International Cooperation
HVO	Haute Vallée du Ouémé (Upper Ouémé catchment)
IFPRI	International Food Policy Research Institute
IMMIH	Institute of Medical Microbiology, Immunology and Hygiene (Cologne)
IMPETUS	Integratives Management-Projekt für einen effizienten und tragfähigen Umgang mit Süsswasser in Westafrika (Integrated Approach to the Efficient Management of Scarce Water Resources in West Africa)
INSAE	L'Institut National de la Statistique et de l'Analyse Economique
IPCC	Intergovernmental Panel on Climate Change
IPCC SRES	Intergovernmental Panel on Climate Change - Special Report Emissions Scenarios
IRD	Institut de Recherche pour le Développement
IS	Information Systems
ITCZ	Intertropical Convergence Zone
ITF	Inter-Tropical Front
InWEnt	Internationale Weiterbildung und Entwicklung gGmbH
LCC	Land Cover Change
LM	Lokal-Modell
LMM	Liverpool Malaria Model
LUCC	Land Use and Cover Change
MAEP	Ministère de l'Agriculture, de l'Elevage et de la Pêche
MODIS	Moderate-resolution Imaging Spectroradiometer
MT	Monitoring Tools
NDVI	Normalised Diffrence Vegetation Index

NOAA	National Oceanic and Atmospheric Administration
ORSTOM	Office de la Recherche Scientifique et Technique d'Outre-Mer
ProPGTRN	Projet Programme de Gestion du Terrain et des Ressources Naturelles
REMO	Regional Climate Model
RUE	Rain Use Efficiency
SBEE	Société Béninoise d'Electricité et d'Eau
SCS	Soil Conservation Service
SDSS	Spatial Decision Support System
SHAB	Service de l'Hygiène et Assainissement de Base
SRTM	Shuttle Radar Topography Mission
SWAT	Soil Water Assessment Tool
TDR-probes	Sensors of Time-Domain Reflectometery
UAV	Ultra light Air Vehicle
UNDP	United Nations Development Programs
UNICEF	United Nations International Children’s Emergency Fund
USGS	U.S. Geological Survey
USLE	Unified Soil Loss Equation
UTC	Universal Coordinated Time
WHO	World Health Organization
WMO	World Meteorological Organization