IMPETUS Westafrikaprojekt

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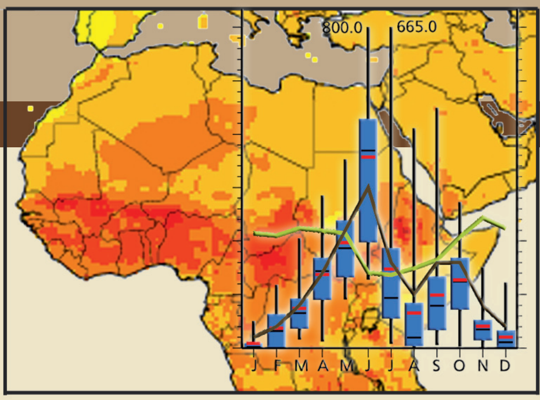
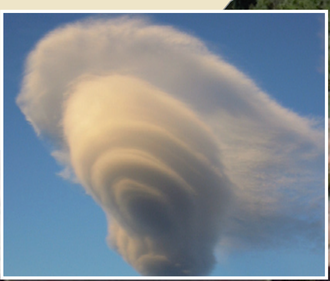
IMPETUS Atlas Morocco

Research Results 2000 – 2007



Third Edition



Universität zu Köln

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

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IMPETUS Atlas Morocco

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 de la Recherche et de la Planification de l'Eau à Rabat, the Direction de la Météorologie Nationale à Casablanca, the Service Eau de Ouarzazate, the Office Régional de Mise en Valeur Agricole de Ouarzazate, and many others. We also thank the student workers Tim Breuer, Ulla Kutsch, Dominique Kohn, Philipp Aben and Arthur Rachowka, who have done a greate job during layouting and map making. Kristina Piecha, Anja Linstädter, Romina Drees and Holger Kirscht proofread the atlas, for which we thank them explicitly.

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

The present third edition is a reprint of the second, major revised edition with some minor corrections.

Oliver Schulz
Michael Judex

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Sand dunes and nomad tent in the southern part of the Middle Drâa Basin.

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 were chosen for their feasible size (< 100.000 km^2), 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 multidisciplinary "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.

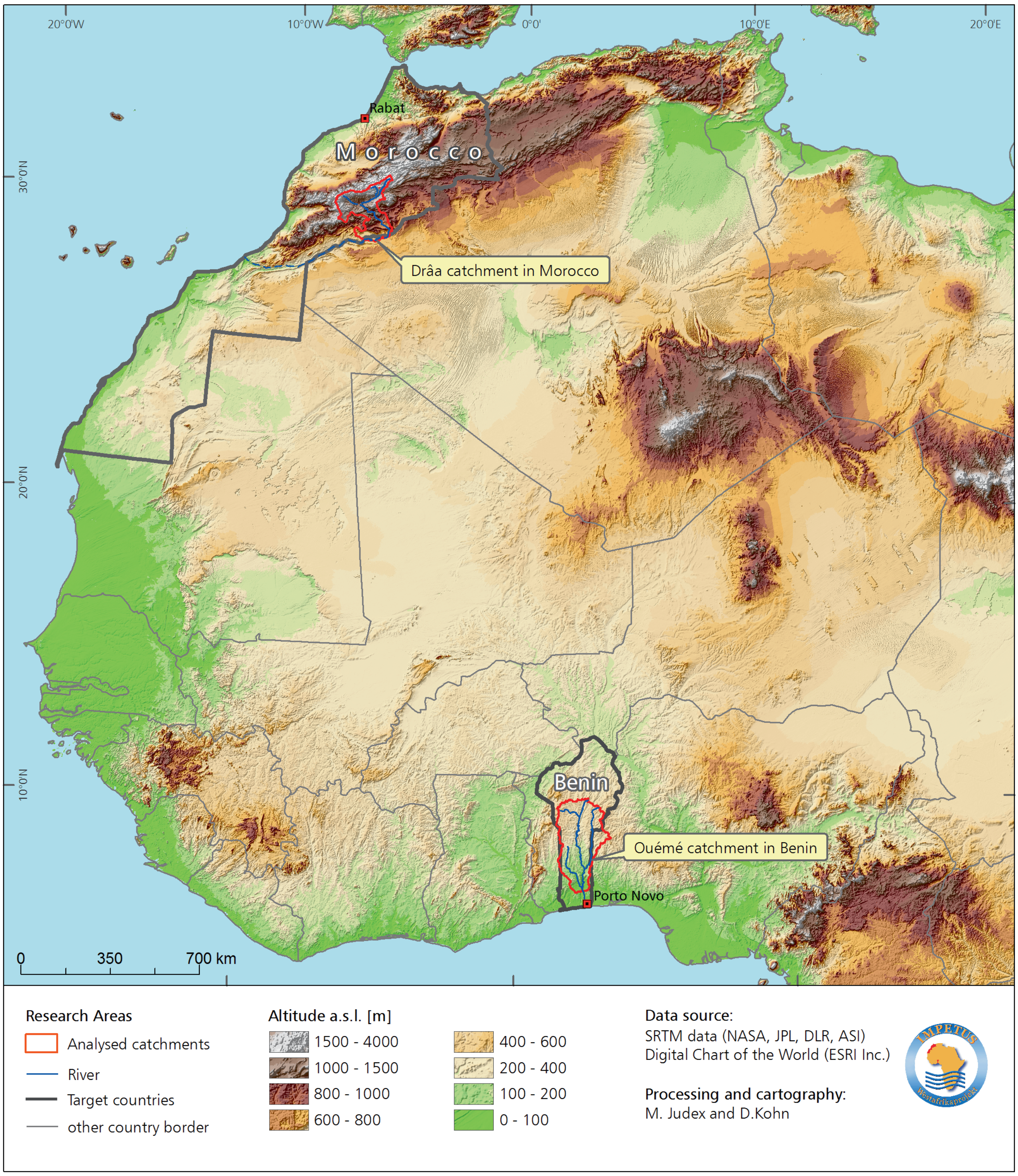

***Fig. 1:** Studied river catchments in West Africa*

2 Morocco

Holger Kirscht and Oliver Schulz

The Kingdom of Morocco (Al Mamlaka al Maghribiya) is located on the north-western edge of North Africa, bordering the North Atlantic Ocean and the Mediterranean Sea. At the transition zone to the Sahara desert, it has common borders with Algeria and Mauritania. Morocco's geography is diverse. The lowlands in the north and between the Atlantic Ocean and the Atlas Mountains are fertile and relatively well developed. Together with the industrialised urban regions around Casablanca and other northern and coastal cities, the lowlands form the economic backbone of the country. The mountainous areas and the region south of the Atlas Mountain chain have long been economically marginalised.

In 2007, Morocco's per capita GDP was $3,800 with an annual growth rate of 2.1%. Today, tourism accounts for Morocco's largest source of foreign revenue, second only to wages sent home by Moroccan workers abroad. In 2000, Morocco entered an Association Agreement with the European Union.

The total population is about 31 million, 51 % of which are younger than 25 years (2008). Ninety-nine percent of the population is Muslim, with small minorities of Christians and Jews. Arabic is the official language, but French is often the language of business, government, education and diplomacy. Approximately 12 million people (40 % of the population), mostly in rural areas, speak Berber.

Fig. 1: *Satellite image of Northern and Central Morocco. MODIS image (23. April 2000, true color) courtesy Jacques Descloitres, MODIS Land Group, NASA/GSFC. Modifications and lettering by O. Schulz. The image is available for download at http://veimages.gsfc.nasa.gov/673/modis-morocco_lrg.jpg.*

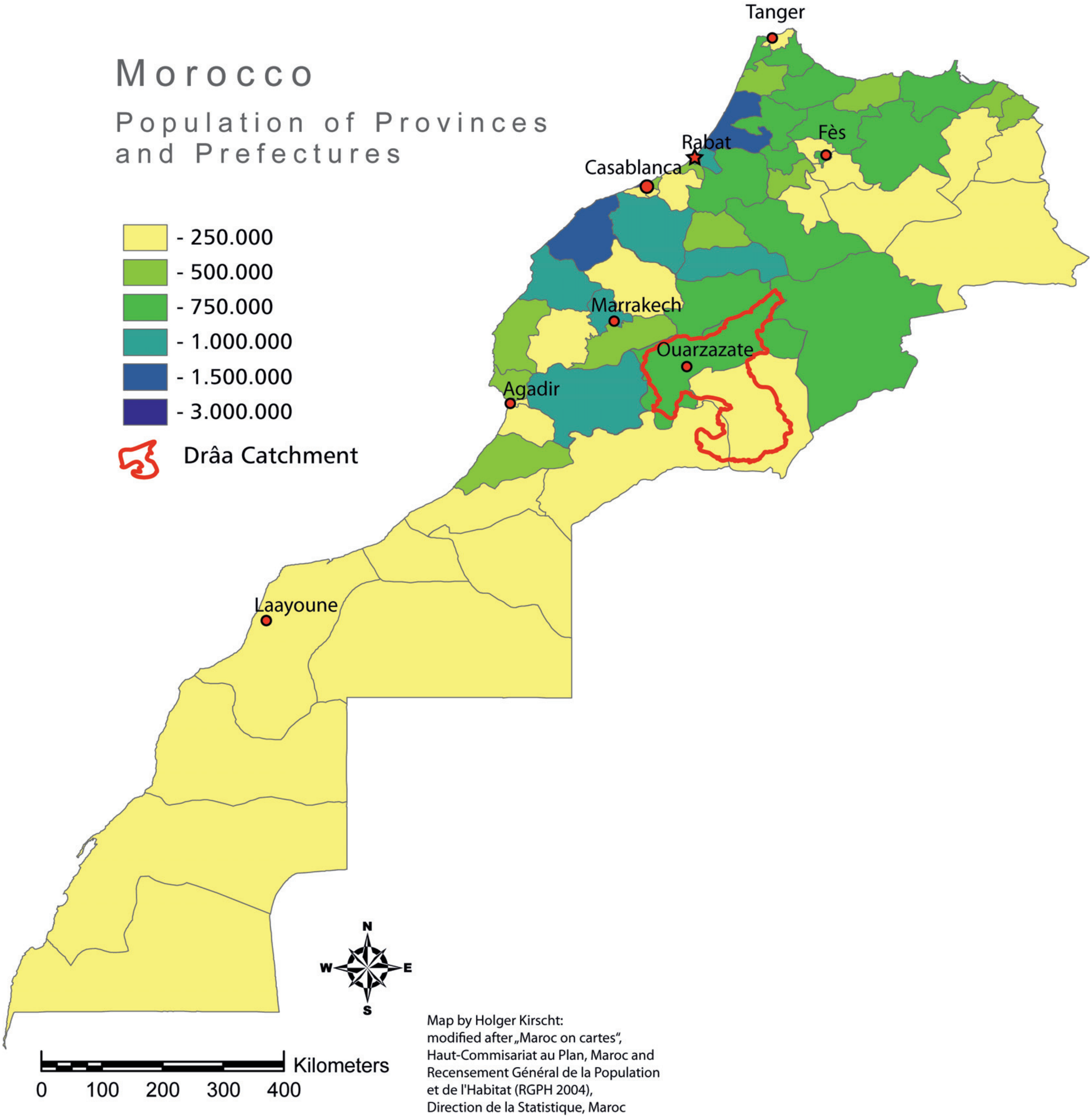

Fig. 2: *Morocco, population of provinces and prefectures.*

From 1912 until its independence in 1956, when Mohammed V ascended to the throne, Morocco was a French protectorate. Today, Morocco is a constitutional monarchy. The present King, Mohammed VI, followed his father Hassan II, who ruled the country as a political and spiritual leader from 1961 to 1999.

Administratively, the country is divided into 16 regions and subdivided into 62 prefectures and provinces led by governors. Below the level of the provinces, 162 "cercles" contain 1497 "*communes*" headed by elected representatives.

3 The Drâa Catchment

Oliver Schulz

The catchment of Wadi Drâa (*Arabic*: Oued Drâa) reaches from the principle mountain divide of the Central High Atlas Mountains southwards to the pre-Saharan foothills. Most of the IMPETUS project work focused on the Upper and Middle Drâa (5°30′ – 7°45′ West and 29°45′ – 32° North), whereas the predominantly dry river bed of the Lower Drâa continues further downstream to the Atlantic Ocean.

The catchment of the Upper and Middle Drâa (size: 28,428 km²) includes the Ouarzazate and Tazenakht basins, six river oases downstream of the reservoir Mansour Eddahbi, parts of the High Atlas and Anti-Atlas Mountains, and parts of Jebel Saghro, Jebel Siroua, and Jebel Bani (*Arabic*: Jebel = mountain) (↗ 10–12; Figs. 1 and 2).

While the Upper Drâa Catchment is part of the Province of Ouarzazate, the Middle Drâa Valley belongs to the Province of Zagora (Fig. 2). The total population of the two provinces is about 780,000, which results in an average population density of 29 people per square kilometre. Besides the fast-growing capital cities Ouarzazate and Zagora (↗ 24, 25), the predominantly Berber and Arab population is concentrated in towns and villages next to tributaries to the Wadi Drâa.

Only the M'Goun and Dadès rivers are permanent throughout the year, with sources fed by enhanced rain and snowfall in the high-mountain north-eastern Upper Drâa catchment. Runoff in the Middle Drâa river bed is controlled by water release (*French*: lâcher) from the reservoir upstream (↗ 17–23).

There is a steep precipitation gradient that follows the topography from the semi-arid High Atlas Mountains in the north (> 700 mm, up to 4,071 m a.s.l.: Jebel M'Goun) to the arid basins and low mountain ranges in the south (~ 50 mm, 450 m a.s.l.: Lac Iriki), whereas air temperature and evaporation increase along the gradient to the xeric pre-Saharan foreland (↗ 4–9).

Vegetation changes according to this climate gradient, from Mediterranean shrublands to Saharan desert biomes (↗ 13). Agriculture is only possible with irrigation, using either canalized river water or pumped groundwater; the latter requires an increasing number of motor pumps (↗ 27–33). Irrigation agriculture is performed on 2 % of the catchment area (total oasis area).

Soils in the Drâa Catchment are little developed and soil salinity is high (↗ 14–16). This causes lower crop yields and quality, especially of date palms in the oases of the Middle Drâa.

Tourism is a growing but limited sector, but declining agriculture and the absence of industry offer only a few jobs for the increasing population. Labour migration, predominantly out of the Drâa Catchment, is common to support families left behind (↗ 26).

An expanding infrastructure of cellular phones, electricity, roads, and central or local water supply systems are forward-looking investments in this remote region of Morocco.

Fig. 1: *Impressions from the Drâa Catchment: Snow covered High Atlas Mountains, primary irrigation channels in the Middle Drâa Valley, irrigation agriculture in the oasis of Tinzouline, sand dunes south of Mhamid (from left to right). Photos: O. Schulz and C. Rademacher.*

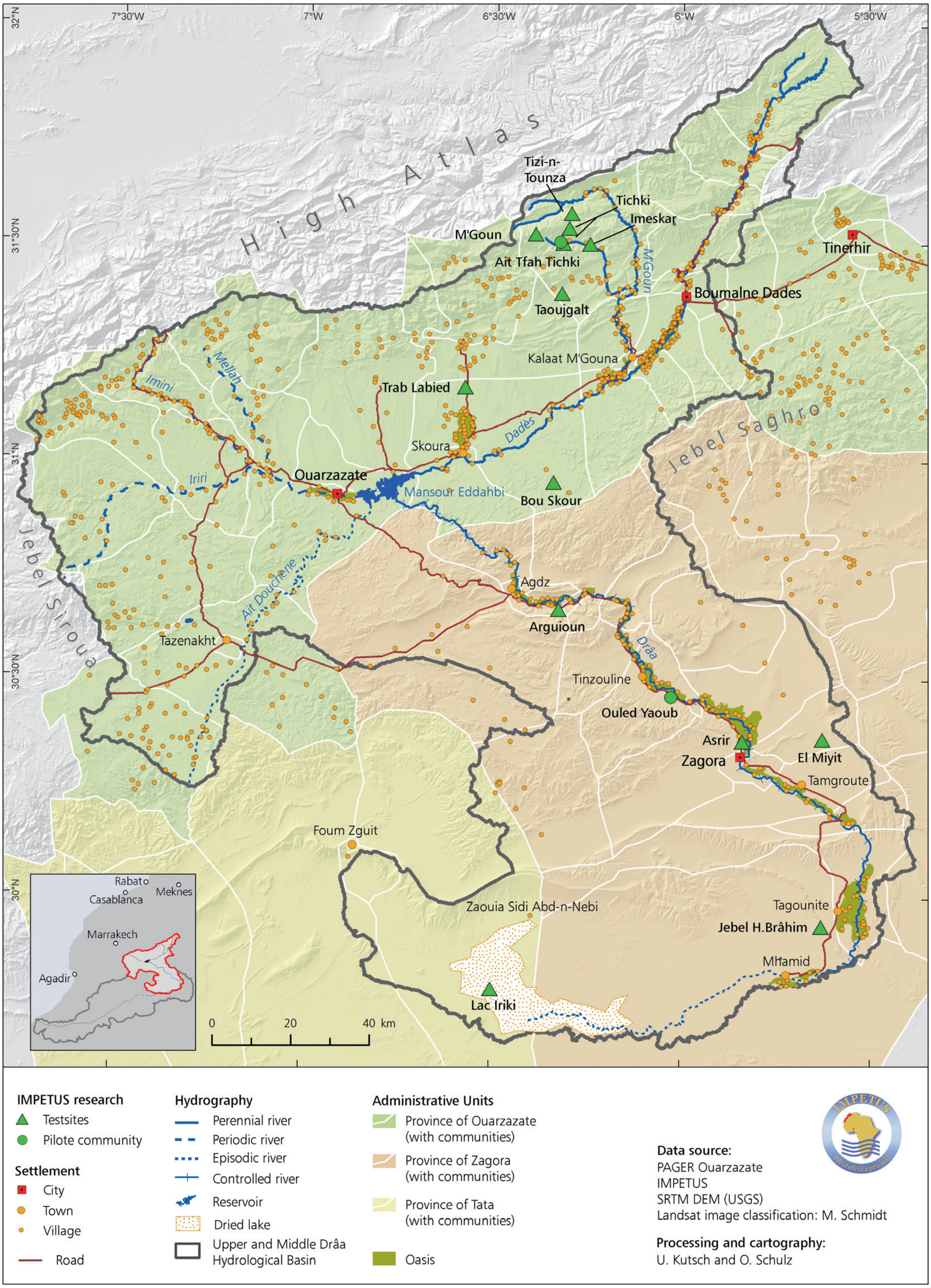

Fig. 2: *Basic map of the Upper and Middle Drâa Catchment.*


Storm in the Basin of Ouarzazate near the Oasis of Skoura.

Climate – Current Conditions and Impacts of Climate Change

4 Precipitation Variability in Northwest Africa

Andreas Fink, Kristina Piecha, Tim Brücher and Peter Knippertz

Quantifying interannual to multi-decadal precipitation variability has a multitude of applications in water-related research and planning. For three homogeneous rainfall regions in Northwest Africa a precipitation index has been calculated for the period 1900 to present.

Introduction

The subtropical climates of Northwest Africa are characterized by a considerable year-to-year and decadal precipitation variability. It is crucial to have a physical understanding of the processes governing climate variations and recent historical climate change in order to assess regional climate projections (Christensen et al., 2007). The creation of a precipitation index time series for three homogeneous rainfall regions in Northwest Africa allows for the quantification of the variability and trends in a key climate parameter. Precipitation data from rain gauges has permitted to cover the period 1900/1901 to 2006/2007 (↗ 5, 6).

Data and Method

The monthly accumulated precipitation data used in this study before 2000 are taken from the Global Historical Climatology Network (GHCN, cf. Vose et al., 1992) dataset, provided by the Office of Climatology of Arizona State University. We selected 37 stations in Morocco and western Algeria with sufficiently long time series. Reports from Moroccan stations obtained from the *Direction de la Météorologie Nationale* (Moroccan Weather Service) were added to close some gaps in the GHCN dataset, especially during the 1980s and 1990s. If only one month within a year had no data, it was filled by the long-term monthly mean, calculated from all data available for the respective month. Updated monthly rainfall totals for the six hydrological years 2000/01 to 2006/07 are based on CLIMAT and SYNOP reports, which is why the number of stations is reduced in recent years (black lines in Fig. 1).

From these monthly station data 12-month annual accumulated rainfall amounts were calculated. As the rainy season in Morocco is the winter half year, these values refer to the hydrological year (September to August of the following year). Since many precipitation stations, in particular semi-arid ones, have non-Gaussian distributions, when monthly or annual precipitation is considered (cf. Nicholson, 1986), the computation of the precipitation index is done on the basis of quintiles. Each 12-month accumulated value is assigned to one of five classes depending on which 20 % portion of the distribution it belongs to (class 1 for the 20 % lowest values, class 2 for the lower 20-40 %, etc.). The precipitation index is defined as the mean of these quintiles averaged over all stations available within one region at a given time. Precipitation index anomalies can then be calculated by subtracting the median value of 3, giving a range of index values from -2 to +2.

Results

Knippertz et al. (2003a) found three homogeneous rainfall regions (Fig. 1): the northern and western parts of Morocco ("Atlantic region" (ATL)), north-eastern Morocco and northwestern Algeria close to the Mediterranean coast ("Mediterranean region" (MED)), and the Moroccan and Algerian stations south of the Atlas mountains ("Atlas region" (SOA)). The time series of the precipitation index (Fig. 1) calculated for the hydrological year reveals considerable interannual and decadal variability: in the MED region, below average rainfall has prevailed since the late 1970s, whereas in the ATL region, precipitation is low from the late 1970s to the early 1990s, but with some wet years during the late 1990s. SOA region precipitation (↗ 7, 8) has been above average in most years after the mid 1980s, especially in the last five years. While the possible eastward shift of the Azores High in climate change simulations suggests a reduction in winter-time precipitation in the ATL and MED regions, the SOA region may receive somewhat higher and more intense rainfalls. This conclusion is inferred from a statistical-dynamical downscaling and the detection of the importance of tropical–extratropical interactions in the present climate (cf. Knippertz et al., 2003b, Knippertz, 2003).

Acknowledgement

We are very grateful to the *Direction de la Météorologie Nationale* for obtaining the reports from Moroccan stations.

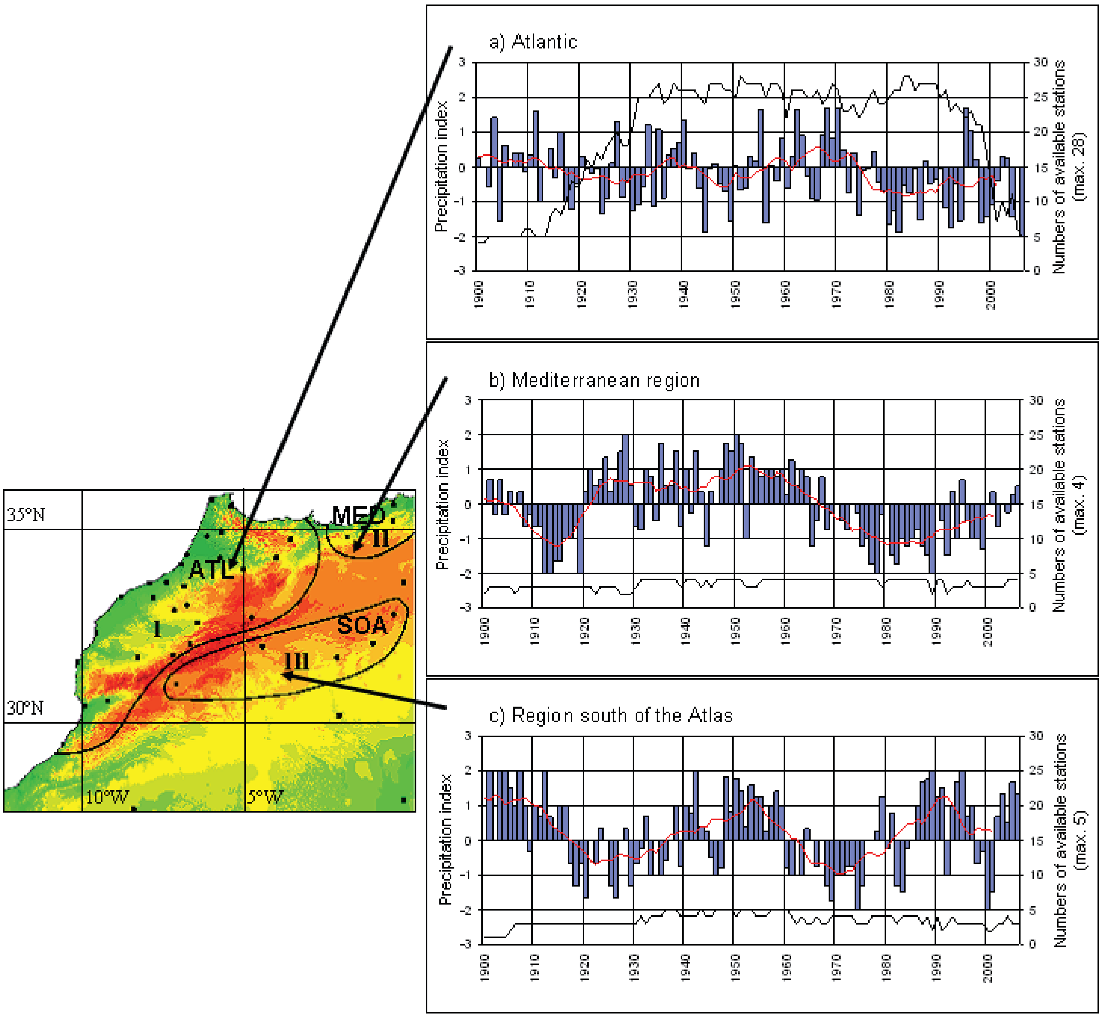

Fig. 1: Precipitation anomalies September–August, 1900/01–2006/07 for the three regions: (I) Atlantic region, (II) Mediterranean region and (III) South of the Atlas (blue bars). The 11-year running mean (thin red lines) and the data availability for the number of precipitation stations used (thin black lines) are also displayed.

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5

Shifting Climate Zones in the Northwestern Maghreb

Kai Born, Kristina Piecha and Andreas Fink

Climates in Morocco range from moderate, influenced by maritime Atlantic and Mediterranean weather systems, to desertic at the northern boundary of the Sahara. We use classical climate classification techniques after Köppen and Walter & Lieth to visualize past and future climate conditions. Future climates are obtained from IPCC climate scenarios using the IMPETUS climate.

Traditional Köppen Climate Classification

The description of climate is based on observational data. These are a starting point for spatial patterns of climate related parameters, which can be calculated using more or less sophisticated interpolation techniques. Two important datasets derived from observations, namely the climate data from the Climate Research Unit of the University of East Anglia (CRU, Mitchell and Jones, 2005) and the VASCLIMO precipitation data (Beck et al., 2005), exist as a gridded product for the entire globe. The CRU data contain information about more climate parameters like humidity, rainfall and temperature, whereas VASCLIMO only consists of precipitation data. To describe climate, the well-known climate classification after Köppen is applied in a reduced version (Guetter and Kutzbach, 1990) to the combined CRU/ VASCLIMO data. Figure 1 shows climate classes for Morocco. In order to provide a view of future climates, the same classification is presented for climate data from regional climate modelling with REMO. For the observational data, the figure shows the displacement of climate zones in the 20th century. For the REMO model (future scenario), the maps reveal a model bias towards dryer climates, but also show that the observed tendency towards warmer and dryer conditions is continued and amplified in the IPCC A1B climate scenario runs.

Zones of Similar Aridity

Climate diagrams describe characteristics of local climates, but are (when applied to station data) only representative at the points of observation. In order to distinguish zones of similar climatic conditions, appropriate indices can be calculated from original climate parameters. In this region, aridity is of major interest. Therefore, we calculated an aridity index from the annual cycle of temperature and precipitation: Here, Tm is the long-term average temperature 2 m above the ground in month m and Pm is the average rainfall sum in that month.

$$A_i = \sum_{m=1}^{12} \{P_m\} - 2 \cdot \{T_m\}$$

Values of Tm and Pm are interpolated using a multiple regression that takes into account exposition and height of the surface on a grid with 1 km resolution. The resulting index is used to define zones characterized by similar aridity conditions. For the period 1961–1990, the zones for the entire northern part of Morocco are shown in Fig. 2.

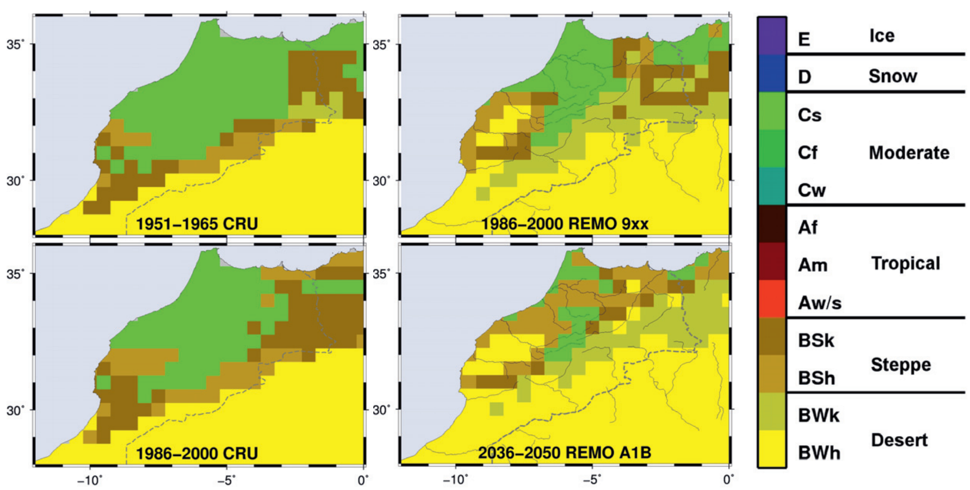

Fig. 1: Köppen climate classification for Morocco. Left two panels: Classification obtained from CRU/VASCLIMO climate data for 1951–1965 and 1986–2000.

Middle: Classification of REMO climate model data for 1986–2000 and for the future period 2036–2050, according to IPCC A1B scenario.

Right: Legend for colours of climate classes.

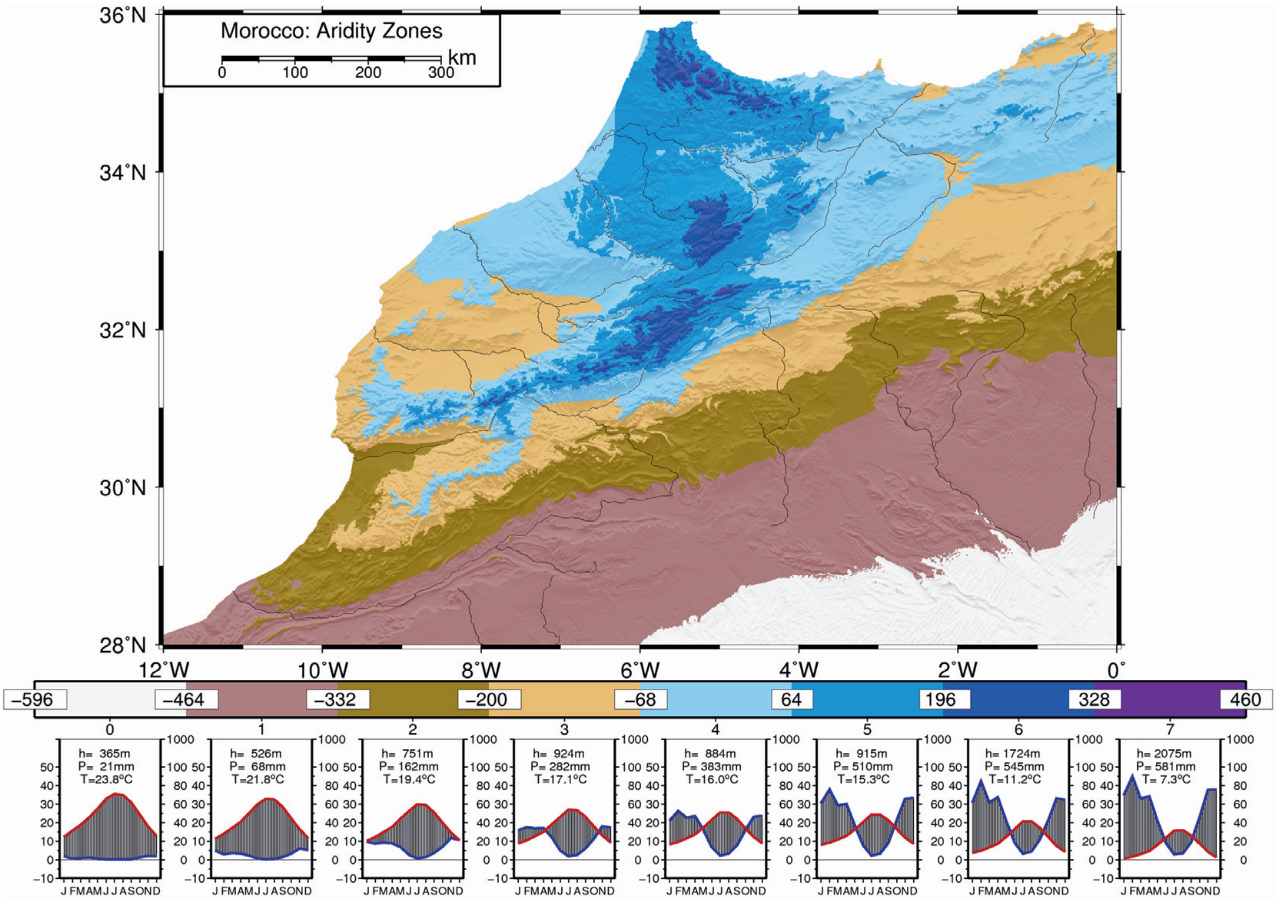

Fig. 2: Zones of similar aridity obtained from CRU/VASCLIMO data (top) and corresponding climate diagrams after Walter and Lieth (bottom) for the period 1961–1990. The colour bar shows climate zone numbers and related aridity index values (boxes). The diagrams contain the average seasonal cycle of temperature (red line), precipitation (blue line) and, as numbers, the mean surface height, annual precipitation and mean 2m-temperature. Note the changing seasonal pattern of monthly precipitation from southeast to northwest.

In addition, the average Walter-Lieth diagrams are drawn for each zone. The transition from maritime to desert climates, as well as from flat and hilly terrain to mountain areas, is reflected in these diagrams.

In addition to the higher temperatures in the south, the seasonal variation (particularly of rainfall) shows a strong heterogeneity between zones. In the northern part, where climate is influenced more by extratropical weather systems, the maximum occurs in late winter/early spring, whereas south of the Atlas Mountains, the maximum occurs in autumn and the amplitude of the seasonal cycle is very small. For extratropical regions in general, wintertime precipitation maxima are associated with maritime climates, whereas climates that are more continental have a maximum in summer due to the higher occurrence of convective rainfall. In southern Morocco, however, this feature is not evident, because the large-scale subsidence of air in the subtropics suppresses convective rainfall during boreal summer. Thus, the seasonal cycle peaks in the transition seasons, as is observed in other subtropical, continental mountains (↗ 4, 5, 8).

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6 Regional Patterns of Rainfall and Temperature in the Drâa Region

Kai Born, Kristina Piecha and Andreas Fink

Climate variability and change affect vegetation, agriculture, and economy in various ways. In order to understand the impact of climate variability in both time and space within the upper and middle Drâa river catchments, we present regional patterns of some characteristics of climate parameters (mainly rainfall and temperature), and discuss present day conditions and changes under IPCC SRES climate scenarios A1B/B1.

Method of Regionalisation

Climate variability is relevant on global and local scales. Knowledge about climate variability on smaller scales is very limited. For past and present times, especially in northern Africa, the density of reliable observations is a critical factor. For future periods, the low spatial resolution of transient climate simulations confines the interpretation of climate scenarios. Downscaling and regionalisation methods can be used to overcome these deficiencies. In general, these methods use statistical relations between larger scale observational or modelling data and local climate conditions. Long-term time series are built that combine large-scale climate forcing and small-scale climate-relevant features. A simple way to regionalise is to use statistical downscaling, in which patterns are refined using multiple linear regressions. In order to assess the effects of smaller scale weather phenomena, the second method, dynamical downscaling, embeds high-resolution atmospheric models into larger scale forcing data from either climate models or observations. The results presented here were obtained using a combination of statistical and dynamic downscaling. In the first step, the regional scale climate model REMO was nested into ECHAM5 global climate model data (Paeth et al. (2005, 2007). The SRES A1B greenhouse gas scenario prescribes global-scale climate change forcing. The subsequent statistical downscaling produces spatially distributed climatic features in the Drâa region (↗ 4).

Assessment of Regional Climate Changes

In order to assess the impact of climate change on vegetation, agriculture and the economy, information about rainfall and temperature characteristics is used. As an example, we present four climate parameters and their possible development under the climate scenario for the upper and middle Drâa catchments. The REMO model output is collected in zones representing similar aridity conditions which reflect most of the climate variability caused by orographic variations (↗ 5).

The following figures present data obtained from REMO model simulations with subsequent statistical downscaling. In all figures the left panel shows the 1986–2000 mean state, the right panel the assessed climate change signal and the small inlet in the right panel spatial patterns of the significance (that the computed change signal is not random but reflects shifting mean values). Statistical significance is calculated using a test based on the Student's t distribution. This test is important for interpreting climate change signals, because a calculated signal may be completely hidden by natural variability and model uncertainty and, thus may not be relevant for climate change impact. Commonly, significance values above 95 % are treated as a reliable signal.

Figure 1 shows the annual mean rainfall of the REMO reference period 1986–2000. It is somewhat smaller than CRU and VASCLIMO datasets suggest (↗ 5, 7, 8), but agrees better with observations in the Drâa region (not shown). In the left panel, the rainfall gradient from southeast to northwest is the most outstanding feature. Rainfall ranges from less than 100 mm for the southern zone to more than 200 mm in the northernmost high mountain area. These values reflect averages over the zones; local rainfall may be much larger. The climate change signal shows overall drying, which is of statistical significance in the mountain area and the southern zone. In the Atlas region, climatic rainfall is affected by the changing behaviour of extratropical weather systems. In the southern zone, rainfall is very low, so the temporal variance is small and produces a relatively high signal to noise ratio.

Another key factor for the vegetation is the number of rainy days. Figure 2 presents the total number of days with rainfall in the Drâa region.

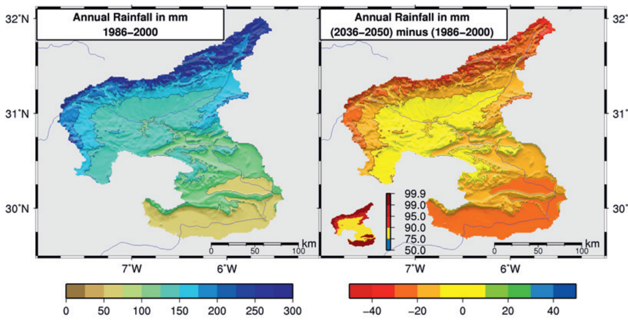

Fig. 1: Annual mean rainfall 1986–2000 in mm (left) and the difference between the periods (2036–2050) minus (1986–2000). The small map in the right panel shows the significance of the climate change signal.

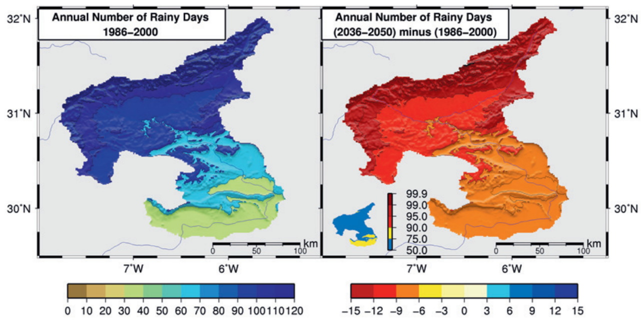

Fig. 2: As Fig. 1, for the number of days with rainfall.

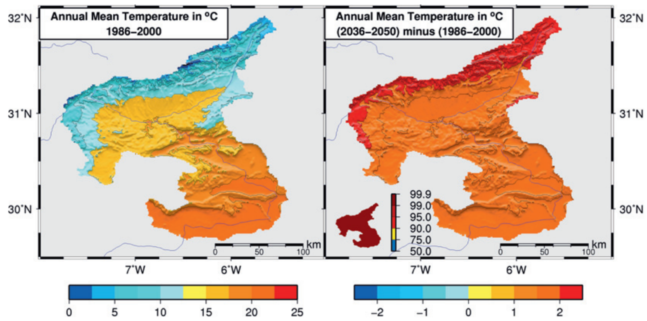

Fig. 3: As Fig. 1, for annual mean temperature 2 m above ground.

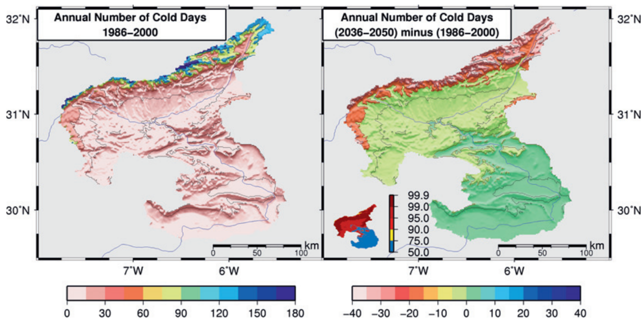

Fig. 4: As Fig. 1 for the number of days with average 2m-temperature below 0° C.

As expected, the patterns of both the mean values and the differences closely resemble the rainfall patterns. Throughout the region, the number of days with rainfall decreases in the climate scenario. Nevertheless, the statistical significance of the change is very small. This indicates that, unlike annual rainfall, slightly different realisations of the climate scenario may even change the sign of the number of rainfall days.

Figure 3 shows the annual mean temperature at a height of 2 m. A warming pattern is clearly significant with strongest changes in the mountains. The estimated warming rate ranges from 1.8 °C/50 years in the southern regions to 2.2 °C in the north. The statistical significance is larger than 99 % for the entire region.

Finally, Fig. 4 shows the number of cold days, defined as days with an average temperature below 0 °C. Only the northern zones show values that are different from zero. As expected, the number of cold days decreases in the SRES A1B scenario. Interestingly, the strongest change is not in the highest elevated zone in the Atlas Mountains, but in the zone covering the valleys south of the Atlas ridge.

In conclusion, the climate scenarios forced by the SRES A1B greenhouse gas scenario produce warmer and, less significantly, dryer conditions in the Drâa region. Although we have to keep in mind that both natural variability and model uncertainty are still very high, the results of regional climate modelling might be understood as a warning: the probability that water stress in the region will increase in the future is considerably higher than we may be comfortable with.

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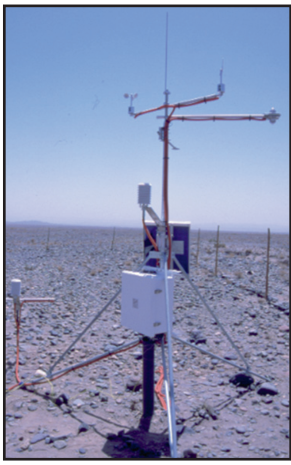
7 The IMPETUS Climate Monitoring Network

Oliver Schulz

Climate monitoring provides important environmental data for analysis, evaluation and modelling of water resources. Therefore, a climate monitoring network following a gradient from the semi-arid High Atlas Mountains to the arid pre-Saharan landscapes was established.

Concept of test sites

Several disciplines work together at the IMPETUS test sites installed at the beginning of the project in 2000. Compromises were made regarding the different demands of the environmental (geology, climatology, meteorology, hydrology, plant ecology, agriculture), and social (cultural anthropology and agro-economy) sciences involved. In general, the test sites are equipped with automatic weather stations (Fig. 1). The sites were selected to cover the variety of main topographic and geological units, following a temperature and aridity gradient from north to south (Figs. 2 and 3) (↗ 5, 6, 9, 12). The initial climate monitoring network has been extended to 13 stations, according to research needs that evolved during the project. Among these stations, the cluster of six stations in the Jebel M'Goun region (1,870 to 3,850 m a.s.l.) is unique for North Africa's high mountains.



Station equipment
- Tripod (3m) + enclosure
- Data logger CR-10X
- Solar panel + battery

Measured elements
- Air temperature + humidity
- Soil temperature + humidity
- Global + net radiation
- Wind speed + direction
- Precipitation

Additional
- Photosynth. active radiation
- Snow depth + temperature
- Surface temperature
- Soil heat flux

***Fig. 1:** Automatic weather station Trab Labied (left), and a list describing the typical configuration.*

Climate differentiation of the Drâa basin

After six years of detailed measurements, the climate and its variability, especially of precipitation, have been quantified (↗ 8, 9). In general, monthly mean air temperatures (2 m-level above the ground) reach their maximum in July and their minimum in January (in February in the high mountain region). While at the M'Goun station the mean air temperature of the warmest month does not reach 10 °C and is less than -10 °C in January and February, the zone of mean temperature above 0 °C in all months begins below 3,000 m. In the Middle Drâa Valley, only single frost days occur and the absolute maximum in the summer reaches 48 °C. The diagrams in Fig. 3 show the precipitation gradient, which is highly correlated with terrain elevation (↗ 9).

Climate monitoring data: applications

Using the measured variables, we calculate temperature and precipitation maps based on conceptual and statistical extrapolations over the whole river basin. Combined with long-term climate data available from the Regional Water Service (Service Eau de Ouarzazate), the IMPETUS data provide input for vegetation analyses and mapping as well as a way to validate meteorological models. Point data of soil temperature and humidity, snow pack, snow surface temperature, and radiation drive and validate detailed physical modelling of hydrological and energy balances (↗ 5, 6, 13, 19, 20, 23).

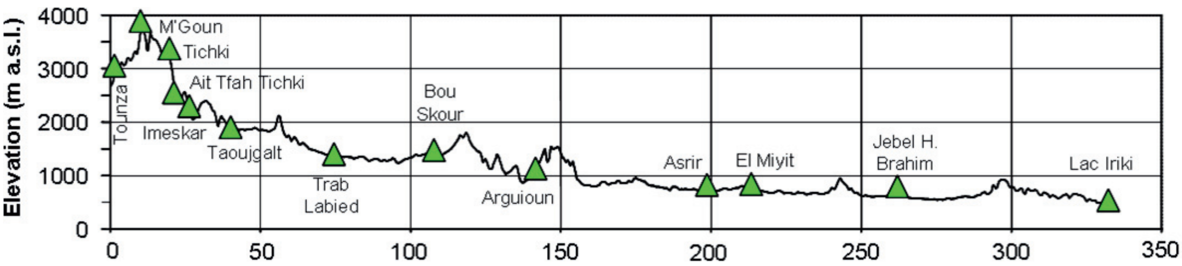


***Fig. 2:** Topographical profile of the 13 IMPETUS test sites and automatic weather stations.*

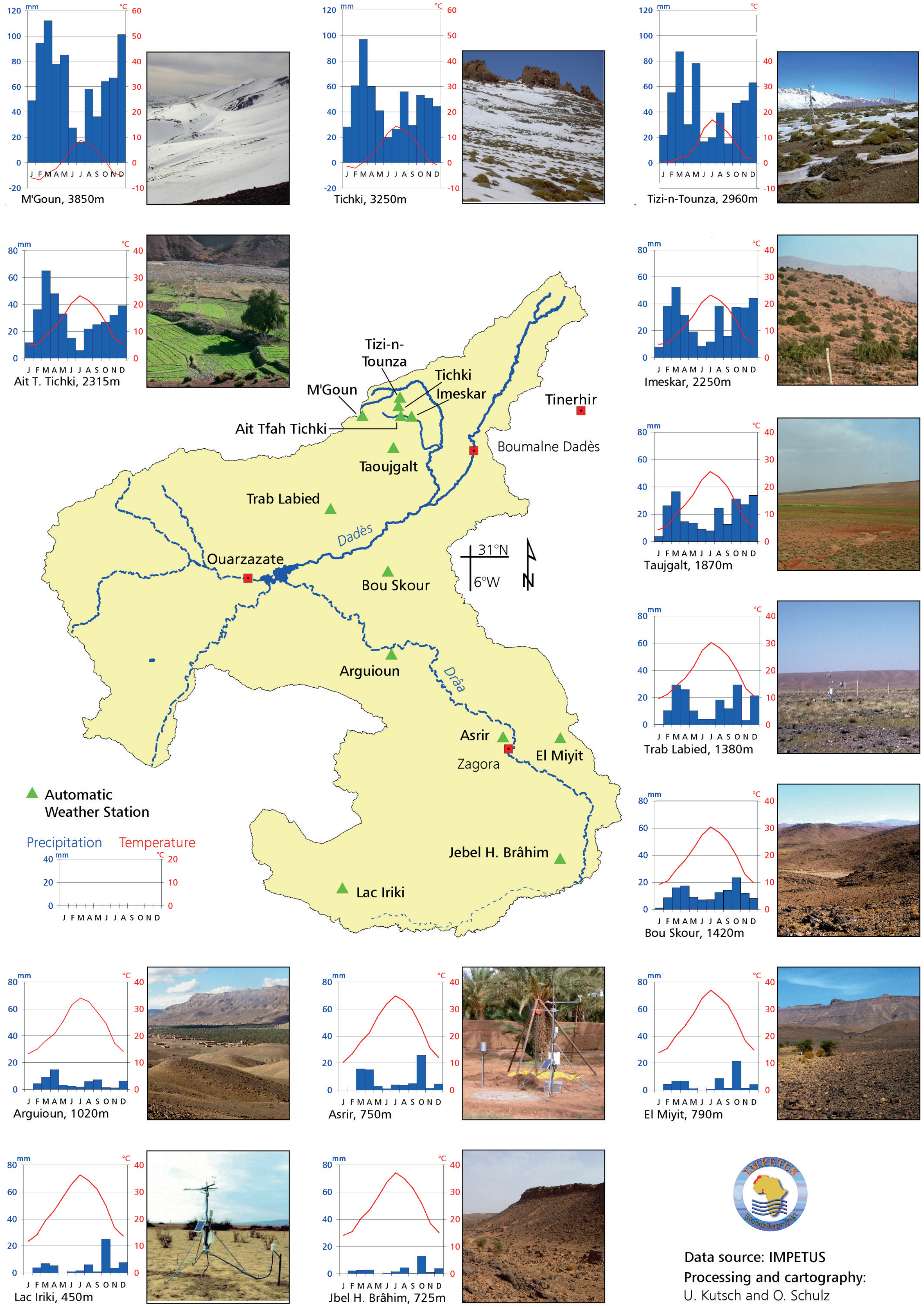


Fig. 3: The IMPETUS climate monitoring network in the Drâa Basin

8 Precipitation in the Upper and Middle Drâa Basin

Oliver Schulz

The climate of the Drâa Basin is affected by its geographical position south of the weather divide of the High Atlas Mountains, which separates the semi-arid to arid Drâa Valley from the more humid Mediterrano-Atlantic climates of northwest Morocco. The southern slopes of the High Atlas still receive considerable precipitation, partly as snow in the winter, whereas the Drâa Valley experiences few but sometimes heavy rainfall events, typical of desert and steppe climates.

Introduction

The spatio-temporal variability of precipitation, including extreme events, affects the local and regional hydrological situation via topography, geological settings, soils and land cover. Thus, precipitation maps can serve as planning tools for water supply (irrigation agriculture, drinking water) as well as a database for scientific analysis and modelling of the regional water balance, including groundwater recharge and the effect of delayed snowmelt on groundwater and river discharge (↗ 19, 20, 23). Precipitation maps can also help to explain patterns of vegetation cover and land use (↗ 13).

Methods

Precipitation in semi-arid and arid regions is generally highly variable. In order to map the average situation, in this case the annual precipitation sum (Fig. 3), it was necessary to include sufficiently long time series of distributed measurements. To obtain the state of the last decades, only data of the period 1984–2004 were selected for data availability reasons. The data were provided by the Regional Water Service (Service Eau de Ouarzazate) for the period 1984–2004 and by the IMPETUS Climate Monitoring Network for 2001–2004. The IMPETUS data were employed to extrapolate data of the official stations (usually situated in the valleys) to the mountainous regions. The gradient calculated (Fig. 1), which connects increasing precipitation (rain and snow) to increasing terrain elevation, is well verified during the overlapping years 2001–2004. The spatial distribution of precipitation was then calculated based on a Digital Elevation Model with a Geographical Information System and smoothed to obtain a graphically improved result (↗ 7, 11).

Precipitation sums and variability

Annual sums range from less than 50 mm in the southern parts of the Drâa Basin to more than 700 mm in the high mountain region of the Jebel M'Goun (Fig. 3, ↗ 7). This can be explained by the increasing distance to the weather barrier of the High Atlas Mountains and by an extremely dry surface layer in the foreland that causes rain drops to evaporate before reaching the valley floors. While the entire Drâa Basin receives (occasionally heavy) precipitation during tropical and extra tropical atmospheric interaction in the spring and autumn,

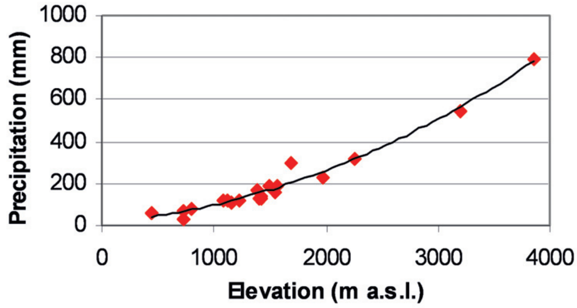


Fig. 1: Precipitation gradient with elevation in the Drâa Basin. Red diamonds mark annual sums at measurement stations (data source: Service Eau and IMPETUS).

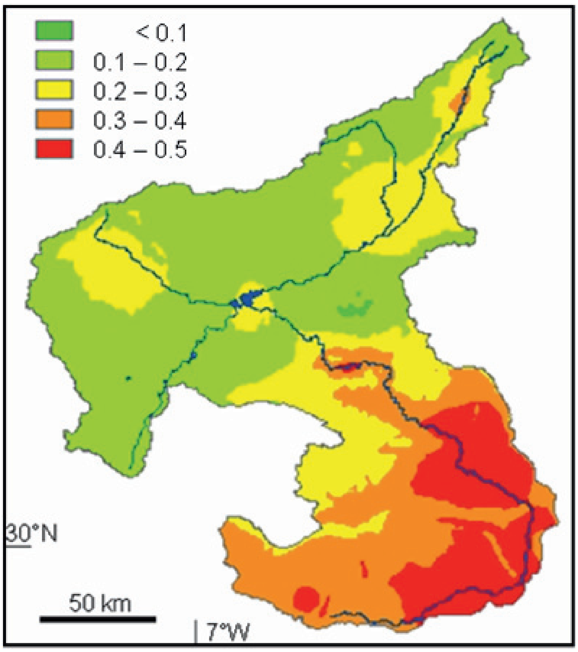


Fig. 2: Coefficient of variation for annual precipitation sums (hydrological years 2001/02–2003/04) in the Drâa Basin.

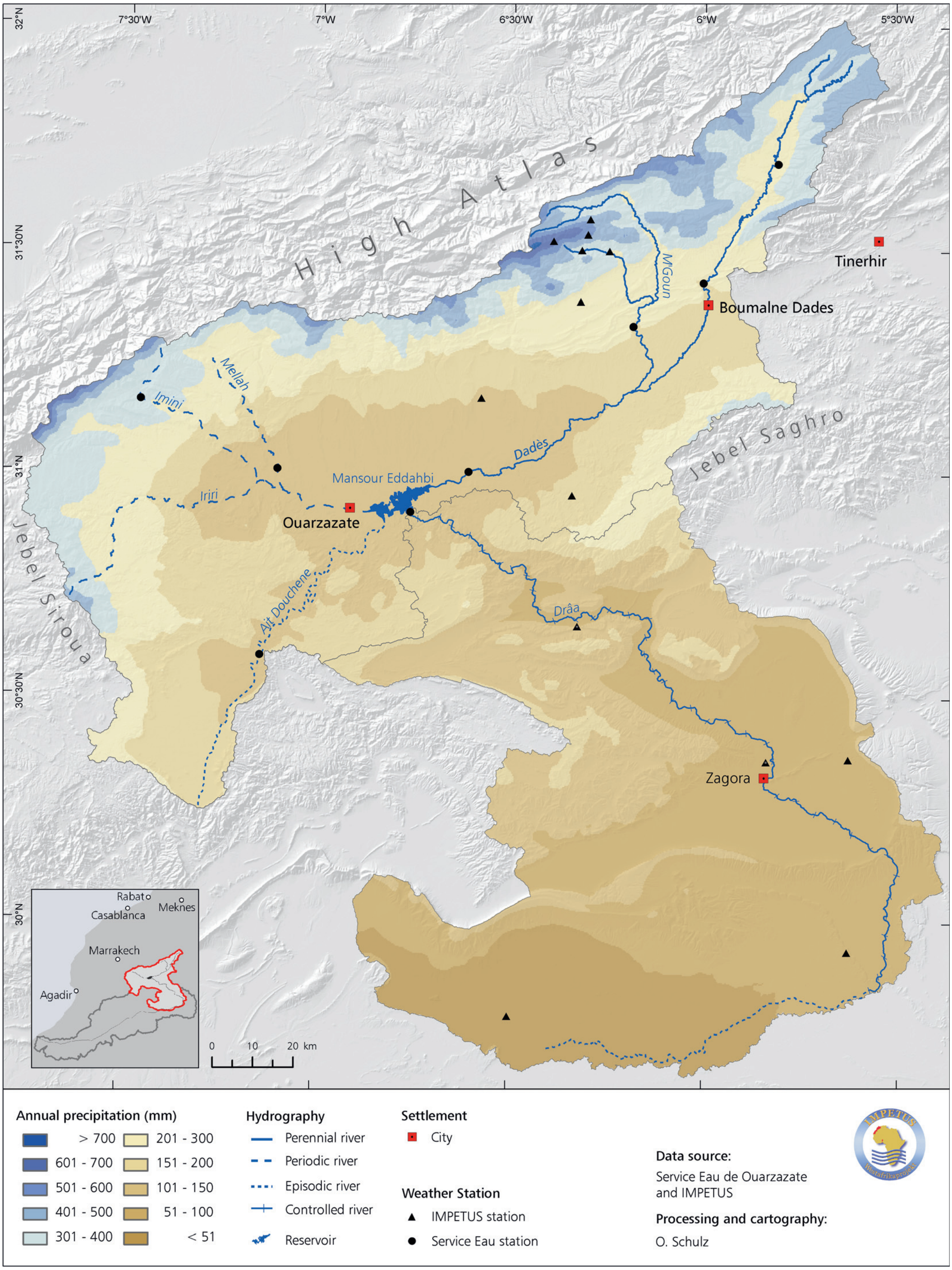


***Fig. 3:** Annual precipitation sums in the Upper and Middle Drâa Basin (1984–2004 average)*

the High Atlas and Upper Drâa Basin receive additional humidity from westward propagating Atlantic winter storms. Further downstream, the "rain shadow effect" becomes increasingly effective. In the Middle Drâa Basin, the variability of precipitation rises as precipitation decreases (Fig. 2) (↗ 4,5,6,9).

9 A Bioclimatic Map for Southern Morocco

Jens Oldeland, Manfred Finckh and Kai Born

This map shows the potential distribution of the Emberger Index for the Drâa Catchment. Its calculation is based on two factors that limit the growth and distribution of plants: temperature and precipitation. First, the thermic range is confined by threshold values such as frost occurrence. Second, total annual precipitation sets the initial value for water balance. The resulting bioclimatic zones can serve as proxies for potential vegetation units.

Introduction

Bioclimatic indices have been developed as tools to explain the spatial distribution of vegetation units by the combination of different climatic factors (Gavilán, 2005). They are increasingly important because they facilitate the transfer of results from climate modelling to land use and vegetation science. They also help predict long-term trends in desertification (↗ 5).

Methodology

The mean minimum temperature of the coldest month (Tm), the mean maximum temperature of the warmest month (TM) and total annual precipitation (P) were derived for the Drâa Basin and its surroundings from Worldclim dataset for the period 1950–2000 (Hijmans et al., 2005). These variables are needed to calculate the Pluviometric Quotient (Q) of Emberger (1930):

$$Q = \frac{(P*2000)}{(T_M + T_m)(T_M - T_m)}$$

In combination with ranges of Tm, this index defines the classification of bioclimatic zones according to a scheme ranging from driest to wettest and hottest to coldest. To calculate the thermic variants we used altitude-adjusted minimum temperature.

Luis Emberger developed this index as a tool to analyse the vegetation zones of Morocco. He later applied it to the whole Mediterranean region where it is still widely used. Daget (1977) refined the classification by more precisely delineating the climatic thresholds of the different classes. These bioclimatic zones were calculated using ArcGIS 9.2 (ESRI).

Bioclimatic Map

Figure 1 shows the distribution of 10 different bioclimatic units within the Drâa Basin. Perarid to arid bioclimates in the temperate to cool thermal variants comprise the largest areas (about 70 %, Tab. 1). These areas generally correspond to vegetation units dominated by the Saharan flora.

Cool to cold, semiarid bioclimates prevail in the mountain ranges of High Atlas and Jebel Siroua, and smaller patches occur in the Antiatlas. In total, these bioclimate classes cover about 20 % of the Drâa Basin. These zones are mainly characterized by ibero-mauritanean Sagebrush-steppes and contain all the important grazing resources for transhumant pastoralists.

Subhumid bioclimates in the cold variant constitute less than 1 % of the area. It is mostly restricted to the highest mountain ranges along the northwestern water divide of the Drâa Catchment. Vegetation of these areas is principally dominated by thorny cushion shrubs that serve as summer pastures for sheep and goats (↗ 10,12,13).

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***Tab. 1:** Area ratio of bioclimatic zones*

variant / bioclimate	cold	cool	fresh	temperate	total area [%]
subhumid	0.4	-	-	-	0.4
semiarid	17.8	2.9	-	-	20.7
arid	6.4	18.2	1.7	-	26.3
perarid	0.8	11.2	17.8	22.7	52.6
total area [%]	25.4	32.3	19.5	22.7	100.0

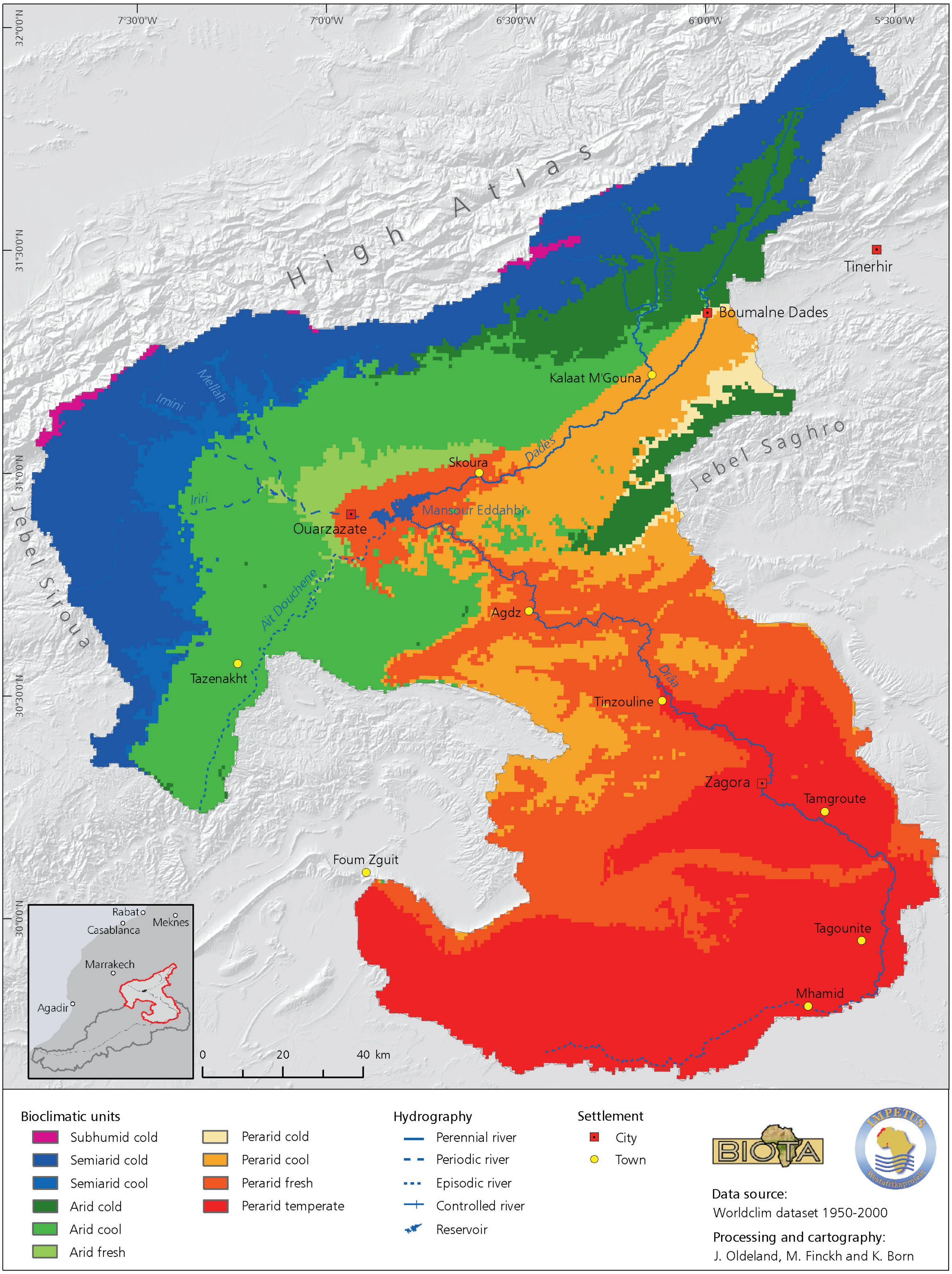

***Fig. 1:** Bioclimatic map of the Drâa Catchment (potential distribution of the Emberger Index)*

Soil erosion forms on the plateau of Taoujgalt/Ait Toumert, Central High Atlas Mountains. In the middle Jebel Aklim (3438 m a.s.l.) and on the left side the snow covered mountain ridge of Jebel M'Goun (4071 m a.s.l.).

Natural Environment

10

Satellite Map of the Drâa Catchment

Pierre Fritzsche

We created a satellite map of the IMPETUS atlas using remote sensing data from Landsat Satellite. The map provides an overview of the Drâa Catchment, showing topography and land cover details.

The following map was created using Landsat 7 ETM+ mosaics from five spatially merged scenes. It is a false composite colour image with a channel combination of 4 (red), 3 (green) and 1 (blue). The map is projected in Lambert Conformal Conical projection, which is the standard IMPETUS projection in Morocco. For visual purposes roads, rivers and the names of high mountain ranges are added, including IMPETUS meteorological stations (↗ 3, 7)

Method

The Landsat program was inspired by Apollo moonbound missions during the 1960s. The Enhanced Thematic Mapper plus (ETM+) used here was introduced with Landsat 7, a joint initiative of the U.S. Geological Survey (USGS) and the National Aeronautics and Space Administration (NASA).

The Landsat time series starts in 1984. It provides the same spectral bands through time to enable consistent land cover change detection (Tab. 1).

Tab. 1: *Landsat 7 parameters*

Swath width:	185 kilometers
Repeat coverage interval:	16 days
Altitude:	705 kilometers
Equatorial crossing:	Descending node; 10 am +/- 15 min
Launch date:	April 1999

When image data is recorded by sensors on satellites and aircrafts, it can contain errors in geometry and measured brightness values of pixels (Richards, 2006). Calibration is done in two steps: on board and on the ground. Sensor calibrations are done with onboard thermal calibration systems (Markham et al., 1997). For ground calibration, the Landsat Processing System (LPS) is used, including radiometric and geometric corrections (Barsi et al., 2003; NASA 2007).

Results

The satellite map is printed as a physical map showing topology, land cover details and the current spatial vegetation distribution. Using wider areas of the solar spectrum enables us to identify and assess, surface materials and their spatial properties (Richards, 2006). Dense vegetation areas, like oases, show up as reddish because of their specific reflectance within the near infrared (Tab. 2). The same mechanism allows us to classify the variability of different areas inside the catchment in detail. These vary from the desert region (white areas south of Jebel Bani) to steppe areas (brown/red, north of Ouarzazate).

The spatial resolution is described as pixel size, depending on the radiometric resolution (Tab. 2).

Tab. 2: *Spectral range and spatial ground resolution of Landsat 7 ETM+ bands*

Band Number	Spectral Range (m)	Ground Resolution (m)
1	.45 to .515	30
2	.525 to .605	30
3	.63 to .690	30
4	.75 to .90	30
5	1.55 to 1.75	30
6	10.40 to 12.5	60
7	2.09 to 2.35	30
Pan	.52 to .90	15

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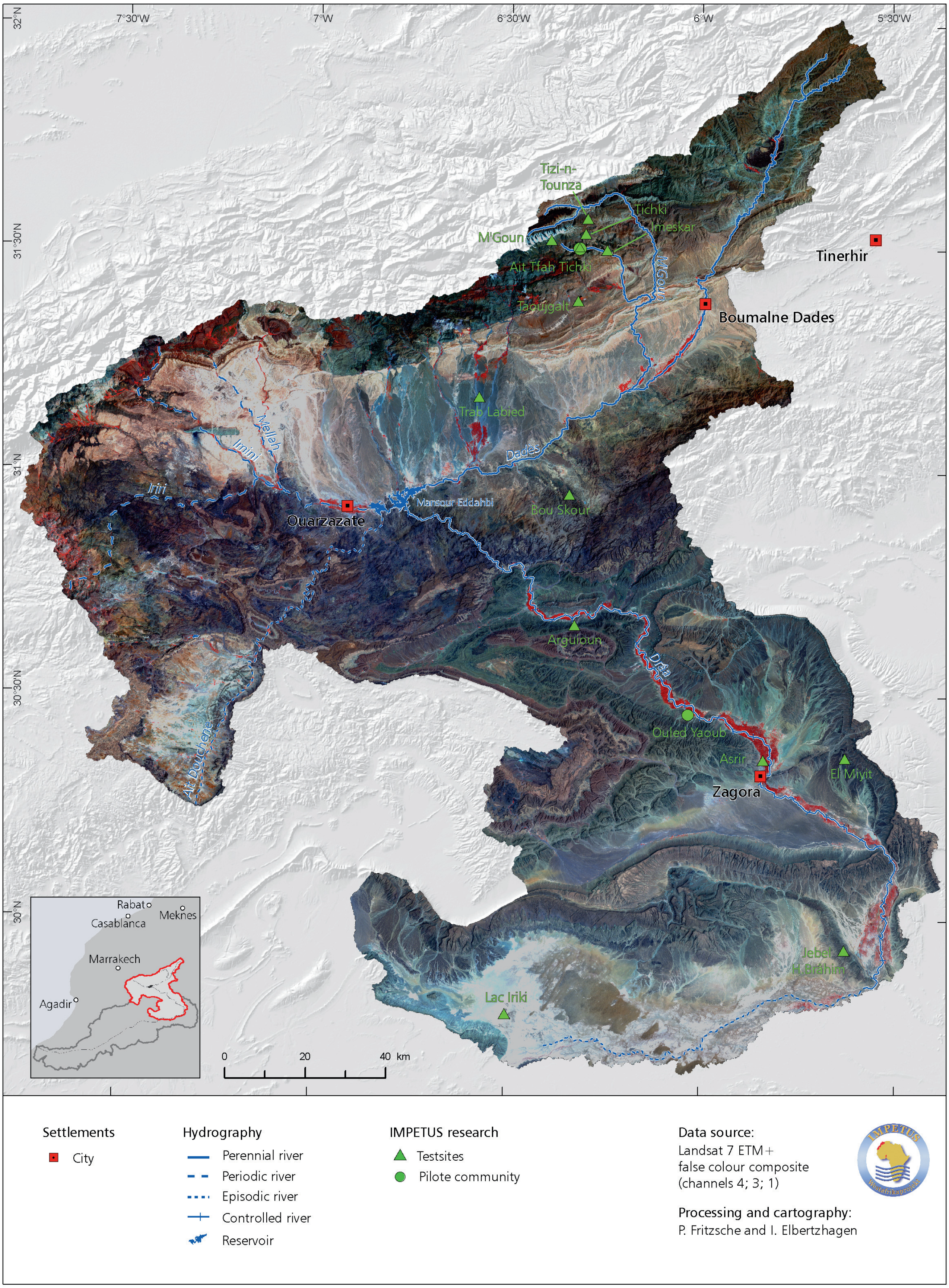

***Fig. 1:** Satellite map of the Drâa Catchment*

11

Digital Terrain Model of the Drâa Catchment

Pierre Fritzsche

The Drâa Catchment (28,428 km²) is characterized by extreme topographic gradients between the high mountain ranges of the High and Anti Atlas in the northern and central part and the extended salty pans with low profiles in the south. The availability of a precise digital elevation model (DEM) is a fundamental prerequisite for almost all disciplines working in a spatial context.

The Drâa Catchment, located in the southern part of Morocco, is characterized by the Atlas and Anti-Atlas ranges and large basins (↗ 3, 12). The following map was created as a physical base map. The DEM (↗ 3, 7) colours grades from green (lower altitudes, starting at 421 m), through yellow, to brownish hues (higher altitudes, maximum at 4,091 m a.s.l.). The latter value closely represents the Jebel M'Goun (4,071 m). The exact locations of the 13 IMPETUS meteorological stations, roads, river network, settlement locations, and the names of the most important mountain ranges are overlain on the DEM. The map is projected in Lambert Conformal Conical projection, which is the standard IMPETUS projection in Morocco.

Method

Digital Elevation Models (DEM) are spatial representations of elevation (highest point below a nominal observer, including buildings, trees and any other objects that protrude from the earth's surface and are resolvable by the observer) at regularly spaced intervals. The DEM used here was set up during the Space Shuttle Radar Topography Mission (SRTM). The height of any point h_t is therefore given by:

$$h_t = h_p - p\cos\left[\sin^{-1}\left(\frac{\lambda\varphi}{2\pi B}\right) + \alpha\right]$$

where hp is the platform height (antenna altitude with respect to the WGS84 reference ellipsoid), p the range, Φ the measured interferometric phase, α the baseline roll angle, λ the observing wavelength, and B the baseline length (Farr, 2007). This measurement includes all protrusions on the surface.

In general, all error sources are taken into consideration while deriving the DEM from SRTM measurements.

The quantified mean error is given by 1.3 m on a 3.8 m standard deviation and a 6 m (90 %) absolute error (Rodriguez, 2006). For the IMPETUS project area, the given root mean square error (rmse) is 18.55 m (r = 0.99), with a maximal variability of 97.14 m, based on measurements of 194 points with a Differential GPS (Klose, in prep.). The DEM used here has an original ground resolution of 90 m, converted to 30 m.

Results

The map shows convolution zones in the area. In addition, the structural salient from the Anti-Atlas range to the pans and basins of the sub Saharan region can be seen. The altitude varies from 4,092 to 427 m a.s.l.

Both the Atlas and Anti-Atlas ranges trend mainly WSW-ENE. The High Atlas forms a natural northern border of the investigation area. These regions are characterized by high topography and a differential network of rivers oriented mainly N-S.

The Basin of Ouarzazate is situated between the Atlas and the Anti-Atlas ranges, identifiable as a depression in greenish hues. The Anti-Atlas range follows at significantly lower altitudes. Southwards, the middle Drâa Valley opens, including the Drâa River and some depression zones (so-called 'feijas') (c.p. Riser, 1988). In the south, the Jebel Bani is a clear landmark before the pre-Saharan basins of Lac Iriki, characterized by low profiles and few altitude changes (↗ 10, 12).

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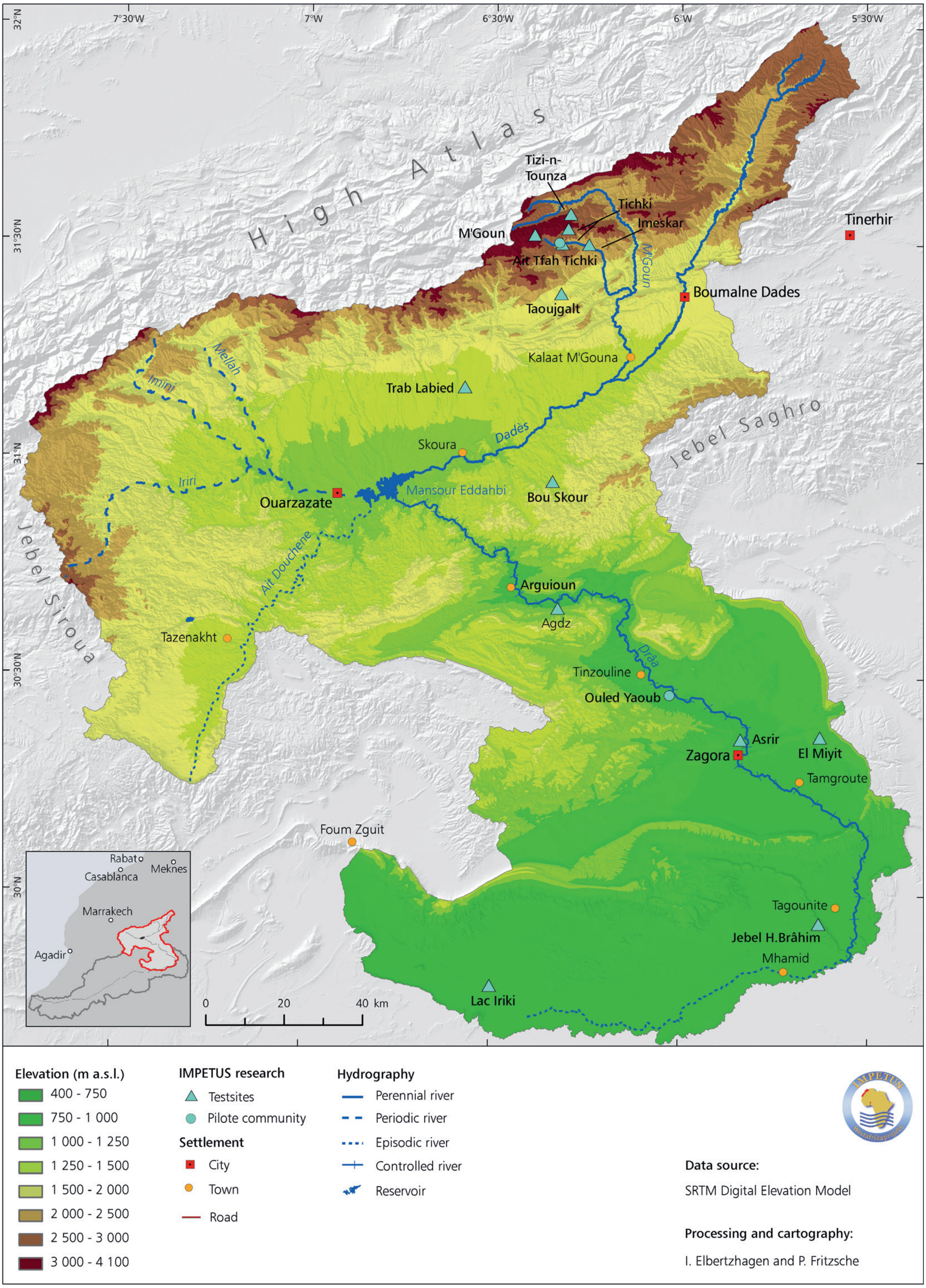

Fig. 1: Digital terrain model of the Drâa Catchment

12

Landscape Units of the Drâa Catchment

Manfred Finckh and Pierre Fritzsche

The map shows the axiomatic landscape units of the Drâa Catchment. They delineate areas with similar climatic, topographic, geomorphologic and edaphic conditions. Thus, they illustrate ecosystems that have comparable environmental constraints and therefore land use potential.

This map is based on the interpretation of the SRTM 30 Digital Elevation Model and Landsat ETM+ false composite images of the Drâa Basin (↗ 10, 11). It was generated using a multi-level approach for landscape classification according to its geographical features (Meynen and Schmithüsen, 1962, Arbeitskreis Standortkartierung, 2003).

Methods

First, landscape classification was based on macro relief and climatic factors. Four macro-units were delimited: the High Atlas, the South Atlas Zone, the Anti-Atlas and the Northern Saharan Zone. These units are equivalent to the modelling zones of IMPETUS (Speth and Christoph, 2003). The Drâa Valley was subsequently designated as a fifth macro-unit due to its unique hydrological and land use patterns of palm oases (↗ 10).

Second, these five zones were split up in 27 natural meso-units according to fundamental geological criteria and relief parameters. In this step, for example, we differentiated between Precambrian and younger mountain ranges of the Anti Atlas (greenish hues), between calcareous and silicate substrates of the High Atlas (red/brown hues), and between ranges dominated by bedrock, and basins filled with sediments (yellow/orange hues) (Riser, 1988). These meso-units represent relatively homogeneous landscapes and thus are useful for spatial planning at a regional scale (↗ 17, 18).

Third, these 27 meso-units were further subdivided according to lithological criteria and substratum. The resulting polygons (or micro-units) confine areas with homogeneous physical conditions and resource availability. They constitute what can be considered reasonable spatial planning units at a communal or local level. They are not displayed in the printed Atlas.

For visual purposes, the meteorological stations of the IMPETUS project and major settlements within the catchment area are shown (↗ 3, 7).

Results

Intensive agriculture occurs almost exclusively in the seven main oases of the Drâa Valley, and to a lesser extent, in river oases in the South Atlas Zone, the High Atlas (e.g., along the Oued Dades, Oued Fintt and the Oued Ouarzazate) and the Basin of Tazenakht. Most of the permanent population and major settlements can be found in these regions (↗ 3,24,25,10).

The semiarid slopes and plateaus of the High Atlas, the Jebel Saghro, and the western Anti Atlas (including the Jebel Siroua) have few permanent settlements but are important grazing resources. The sedimentary mountain ranges south of the Jebel Saghro belong to arid desert ecosystems and have very little pastoral value. Most pastoral activity south of Jebel Saghro occurs on wadis and in the intercalated basins, e.g., the basins and feijas around Zagora, Tagounite and Foum Zguid. In the last few decades, pastoralists have increasingly had to share such resources with small farms, irrigated via diesel pumps (Werner, 2006) (↗ 9, 13, 27, 28, 29, 30).

A tourist resource of growing economic importance are the sand dunes (Ergs) of Mhamid and Cheguaga and the salt plains of Lac Iriki. These areas are visited by tour operators from Marrakech, Agadir, Ouarzazate and Zagora. A national park project for this area is in progress.

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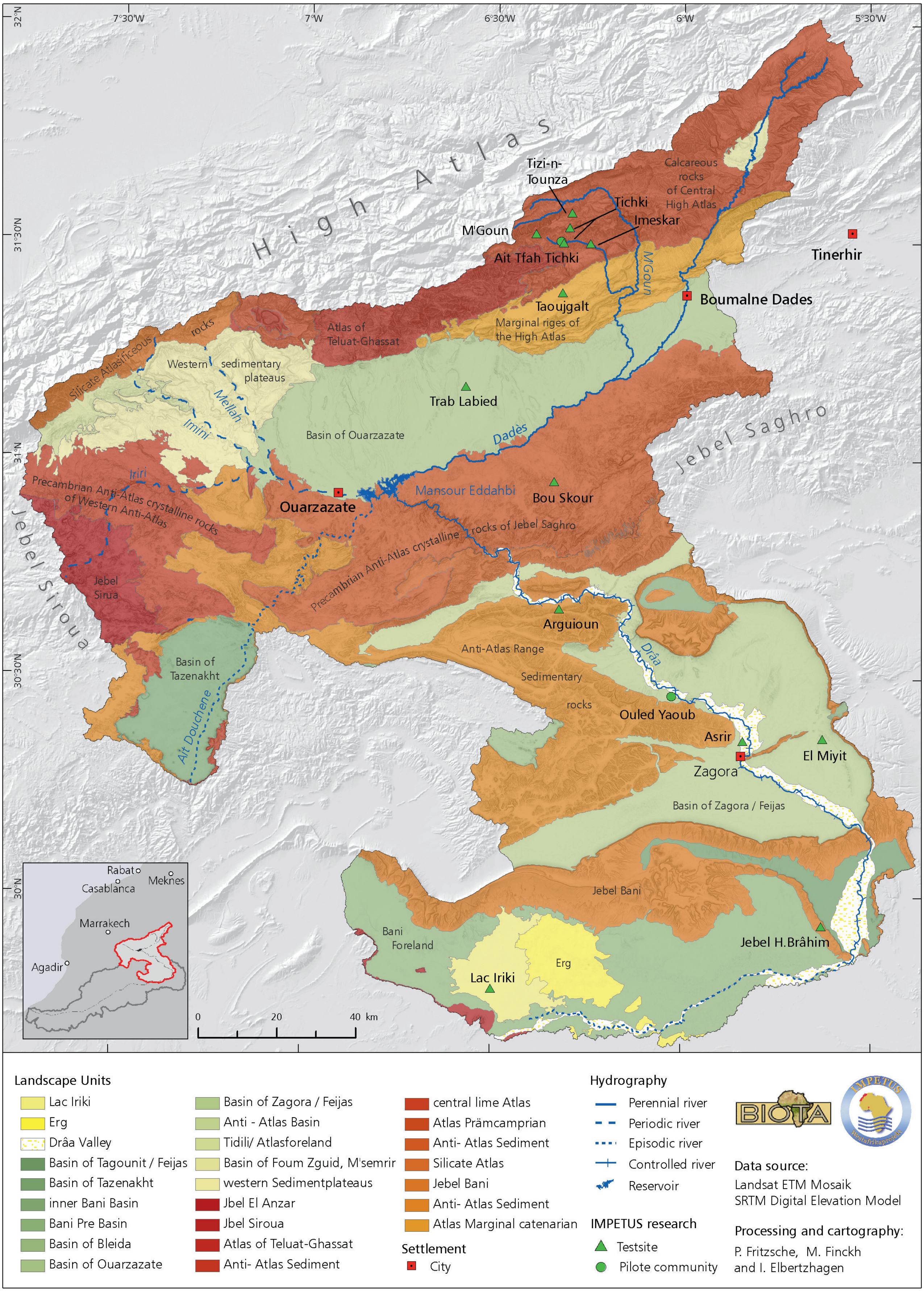

***Fig. 1:** Landscape units of the Drâa Catchment*

13 Vegetation Map of the Drâa Basin

Manfred Finckh and Peter Poete

The vegetation of the Drâa basin is a transition zone between Mediterranean shrublands and Saharan desert biomes. From the High Atlas southward, vegetation follows a joint altitudinal and aridity gradient that results in a sharp transition from subhumid to arid ecosystems. Human land use alters natural vegetation patterns to varying degrees of degradation intensity.

Floristic regions

Three large floristic regions contribute to the phytodiversity of the Drâa Catchment (Fig. 1).

The high elevations of the High Atlas, Jebel Siroua and Jebel Saghro (from ca. 2,200 m up) are covered by Oromediterranean ecosystems (↗ 9). Their floras principally originated from Mediterranean sources. The vegetation is dominated by thorny cushion shrubs, a life form that reflects both microclimatic and anti-herbivore adaptations.

Three Juniper species (Juniperus thurifera L., J. oxycedrus L. and J. phoenicea L.), partly intermingled with oak (Quercus rotundifolia Lam.) and ash (Fraxinus xanthoxyloides Wall.) trees, were originally found in a transition zone bordering with the sagebrush steppes. This southern margin of evergreen Mediterranean forest is now heavily degraded and overused. Only a few Juniper woodlands still remain.

The southern slopes of the High Atlas between 1,400–2,400 m asl, as well as a similar altitudinal belt in Jebel Siroua and Jebel Saghro are covered by Ibero-Mauretanian sagebrush steppes with dwarf shrubs including Artemisia herba-alba Asso, A. mesatlantica Maire, Teucrium mideltense Humb., and perennial grasses including Lygeum spartum L.and Stipa spp. A multitude of annuals emerge in spring and these contribute to the remarkable floristic richness of this steppe biome. The steppes have a pronounced continental character and cover vast extensions in the Eastern Moroccan Highlands.

Pre-Saharan and Saharan flora constitute the third important element in the Drâa area. Pre-saharan semi-deserts and rock steppes with Convolvulus trabutianus Schweinf. and Muschl. and Hammada scoparia (Pomel) Iljin begin to appear in the Ouarzazate Basin and the lower belt of the Jebel Saghro. However, they are principally situated in the southern sedimentary chains of the Anti Atlas and its intercalated basins. Hammada scoparia alone dominates pediments and loamy soils; less dominant annual and geophytic species occur here in the spring.

Below approximately 1,000 m asl, wadi vegetation is dominated by trees (e.g. Acacia raddiana Savi, A. ehrenbergiana Hayne, Maerua crassifolia Forssk.) and perennial C4-grasses (e.g., Panicum turgidum Forssk., Pennisetum dichotomum Delile) of Sahelic origin. The bimodal precipitation regime of the southern Drâa region, with rainfall maxima in the late spring and early autumn, permits the existence of species with summer-rainfall adaptations (↗ 3, 7).

Extrazonal vegetation along watercourses and agricultural systems show a similar transition from Mediterranean to Saharan ecosystems. The water courses in the High Atlas above ca. 2,000 m are accompanied by scattered fragments of sub-mediterranean alluvial forests with Fraxinus angustifolia Vahl, and species of Populus and Salix. These native habitats are now mostly replaced by cropland and apple or walnut orchards. Between 2,000–1,200 m asl, there is Mediterranean alluvial vegetation with Nerium oleander L. and Tamarix spp., or Mediterranean orchards with almond, caroub and olive trees. Below 1,200 m, river terraces are covered by Tamarix amplexicaule Ehrenb., and oasis vegetation is dominated by the Saharan date palm (Phoenix dactylifera L.).

Finally, the Drâa Catchment (↗ 12) includes important areas of azonal character such as the salt pans of Lac Iriki. These salt pans contain ephemeral halophytes (e.g., Frankonia pulverulenta L., Mesembryanthemum nodiflorum L.). Other azonal areas include the dune fields of the Erg Chegagua, with sand specialists such as Aristida pungens Desf., Calligonum polygonoides L., Tamarix aphylla (L.) Karst and, on ruderalized sites, Calotropis procera (Aiton) Aiton fil.

Human impacts influence not only the irrigated lands, but also semiarid and subhumid steppe ecosystems (↗ 10). Firewood collection and continuous overgrazing have resulted in the general degradation of these ecosystems.

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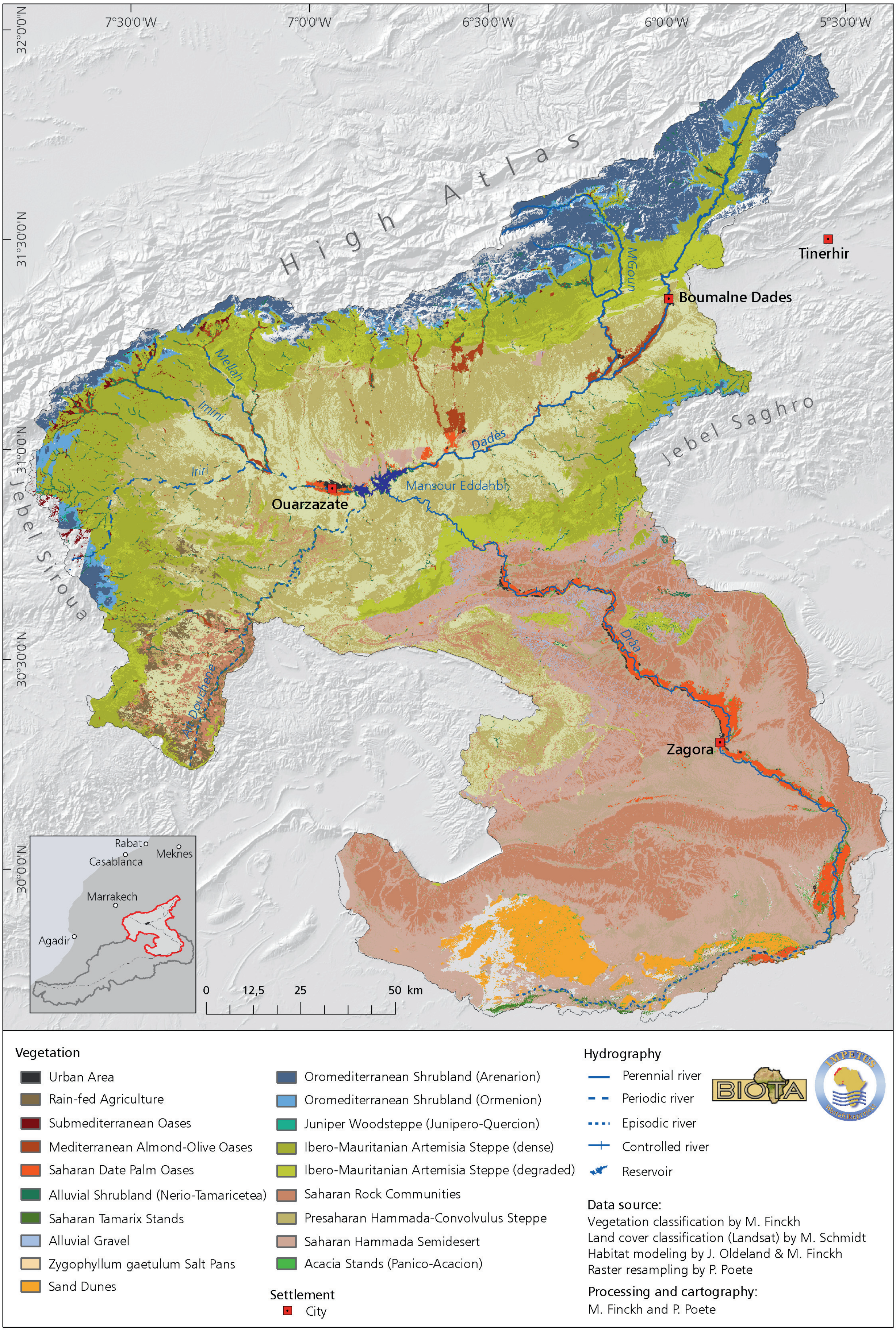

***Fig. 1:** Vegetation map of the Drâa Basin*

14 Soil Properties in the Drâa Catchment

Anna Klose

The availability of soil information in the Drâa Catchment is restricted to the oasis areas under irrigation agriculture, covering approximately 2 % of the catchment. Effective management of land use and soil resources requires knowing the spatial distribution of soil. Consequently, maps of soil properties are derived from soil profile data and empirical relationships with available environmental data.

Soil profile data

211 soil profiles within the Drâa Catchment, originating from the ROSELT/OSS (HCEFLCD, 2004) and IMPETUS projects, were analysed to determine the skeleton content, texture, carbonate, organic carbon, nitrogen content and pH. In order to derive soil hydraulic properties, pedotransfer functions were applied including a correction for skeleton content. The profiles are classified according to the World Reference Base for soil resources (WRB) (↗ 15,16).

Regionalisation of soil properties

The CORPT approach is based on analyzing the relationships between soil properties and the five factors of soil formation (climate, organisms, relief, parent material and time; Jenny, 1941). The known parameters representing these factors are temperature and precipitation (C), vegetation type (O), various terrain attributes deduced from a digital elevation model (R) as well as attributes of the geological map 1:500,000 (P) (↗ 8, 11, 13, 18). Information on time (T) is not available. Multiple linear regressions including dummy variables (the latter accounting for nominal parameters) are used to evaluate the relationship statistically. The results of the analysis are summarised in Tab. 1. The regression equations were used to generate maps of soil properties (examples in Figs. 1, 2 and 3).

Tab. 1: *Statistical values of the measured soil properties and regionalisation quality*

Soil Property	Mean	SD	R^2	RMSE
soil depth [cm]	85.59	66.93	0.47	49.22
top depth [%]	43.59	28.71	0.42	22.42
top stone content [%]	43.49	23.42	0.79	10.77
top sand [%]	44.87	20.04	0.57	13.29
top silt [%]	37.93	16.71	0.47	12.26
top clay [%]	17.13	9.38	0.69	5.18
top CaCO3 [%]	11.80	12.68	0.49	9.43
top org. carbon [%]	0.67	0.72	0.56	0.48
top nitrogen [%]	0.06	0.07	0.58	0.04
top pH	8.45	0.48	-	-
sub depth [%]	64.42	20.57	0.52	14.28
sub stone content [%]	48.83	25.73	0.54	17.41
sub sand [%]	42.45	21.51	0.55	14.41
sub silt [%]	36.82	16.71	0.56	11.07
sub clay [%]	20.70	11.20	0.56	7.44
sub CaCO3 [%]	17.19	16.80	0.35	14.25
sub org. carbon [%]	0.52	0.59	0.84	0.24
sub nitrogen [%]	0.06	0.10	0.89	0.03
sub pH	8.41	0.49	0.64	0.29

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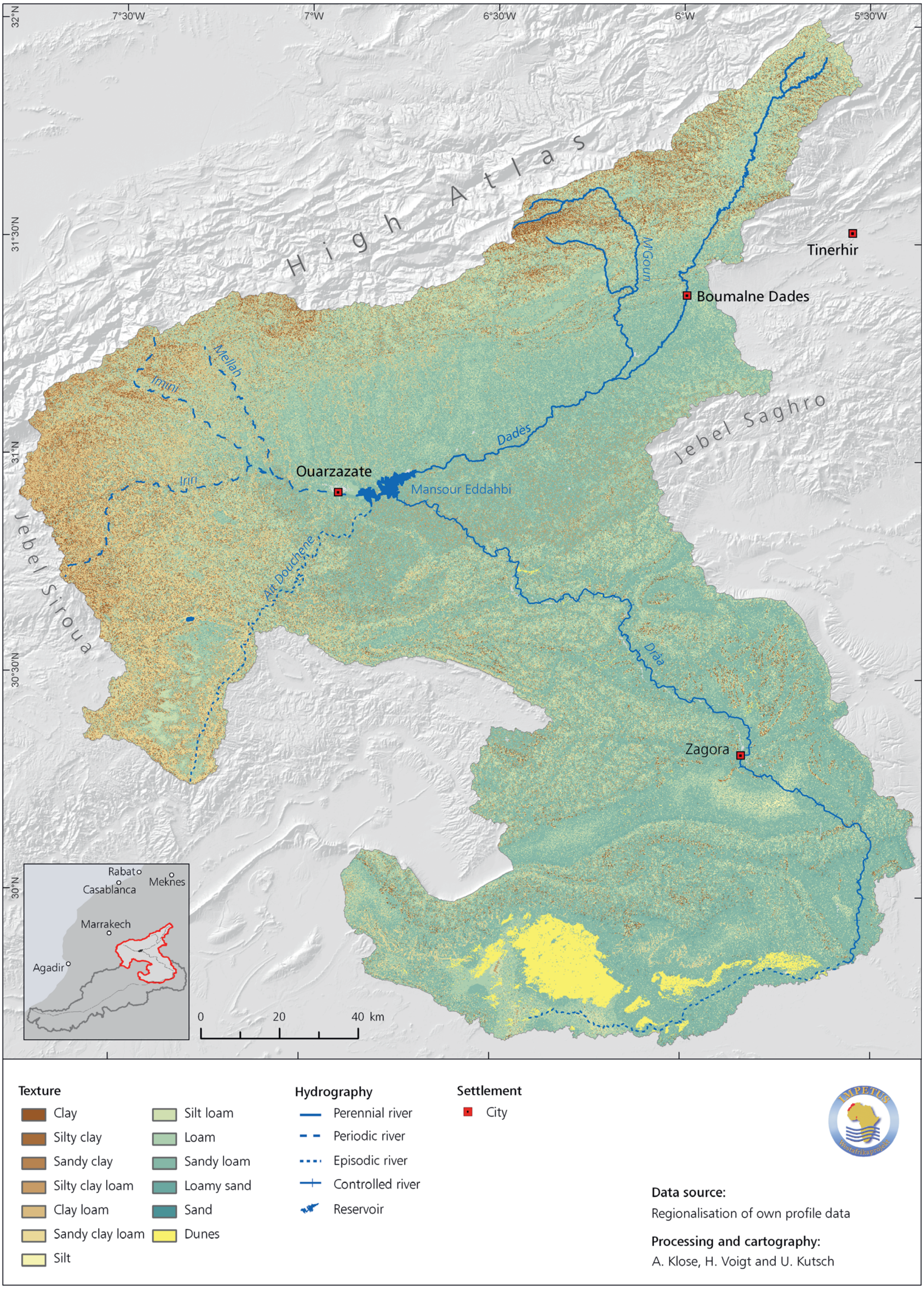

Fig. 1: Topsoil texture in the Drâa Catchment

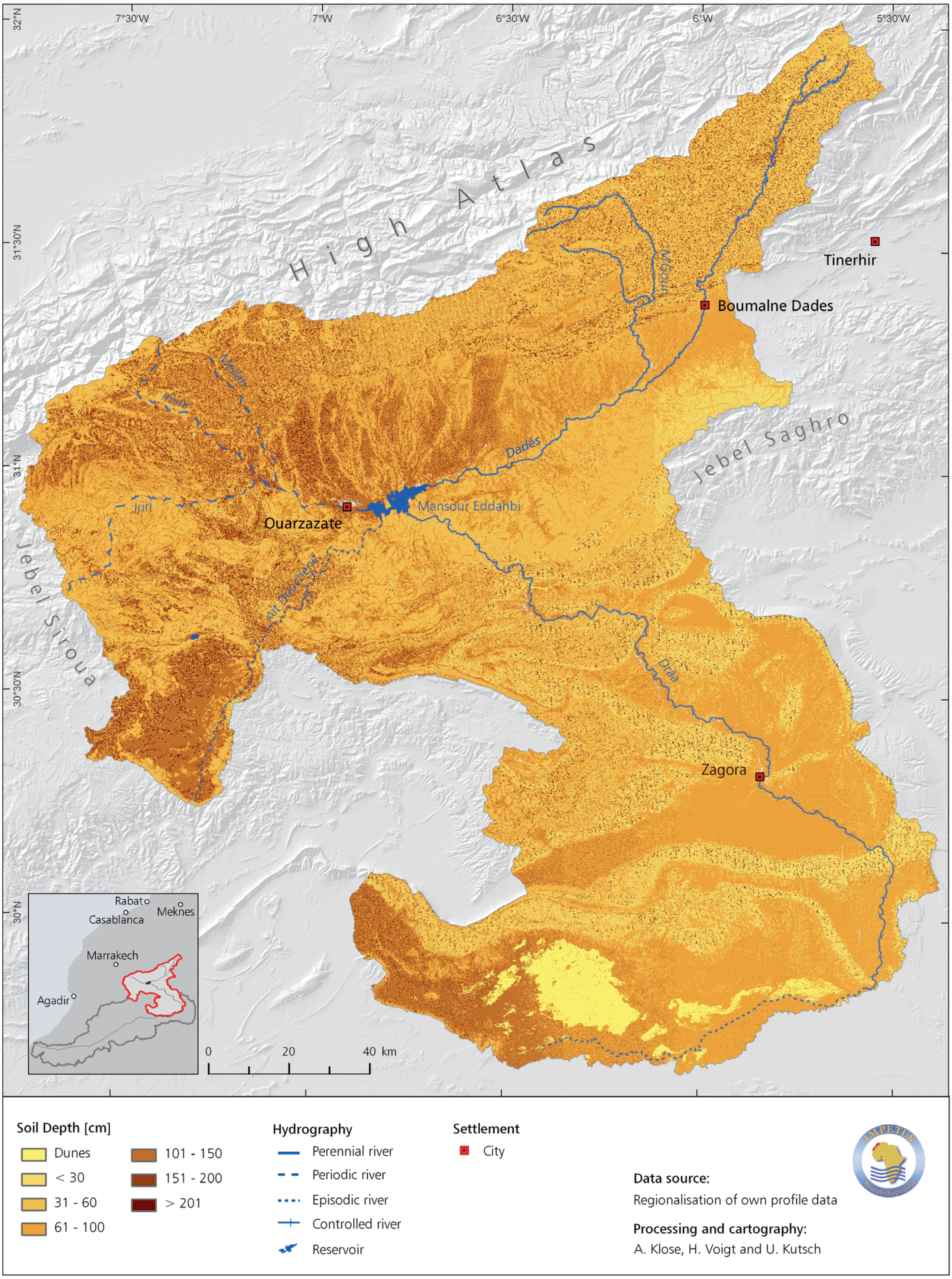

***Fig. 2:** Soil Depth in the Drâa Catchment*

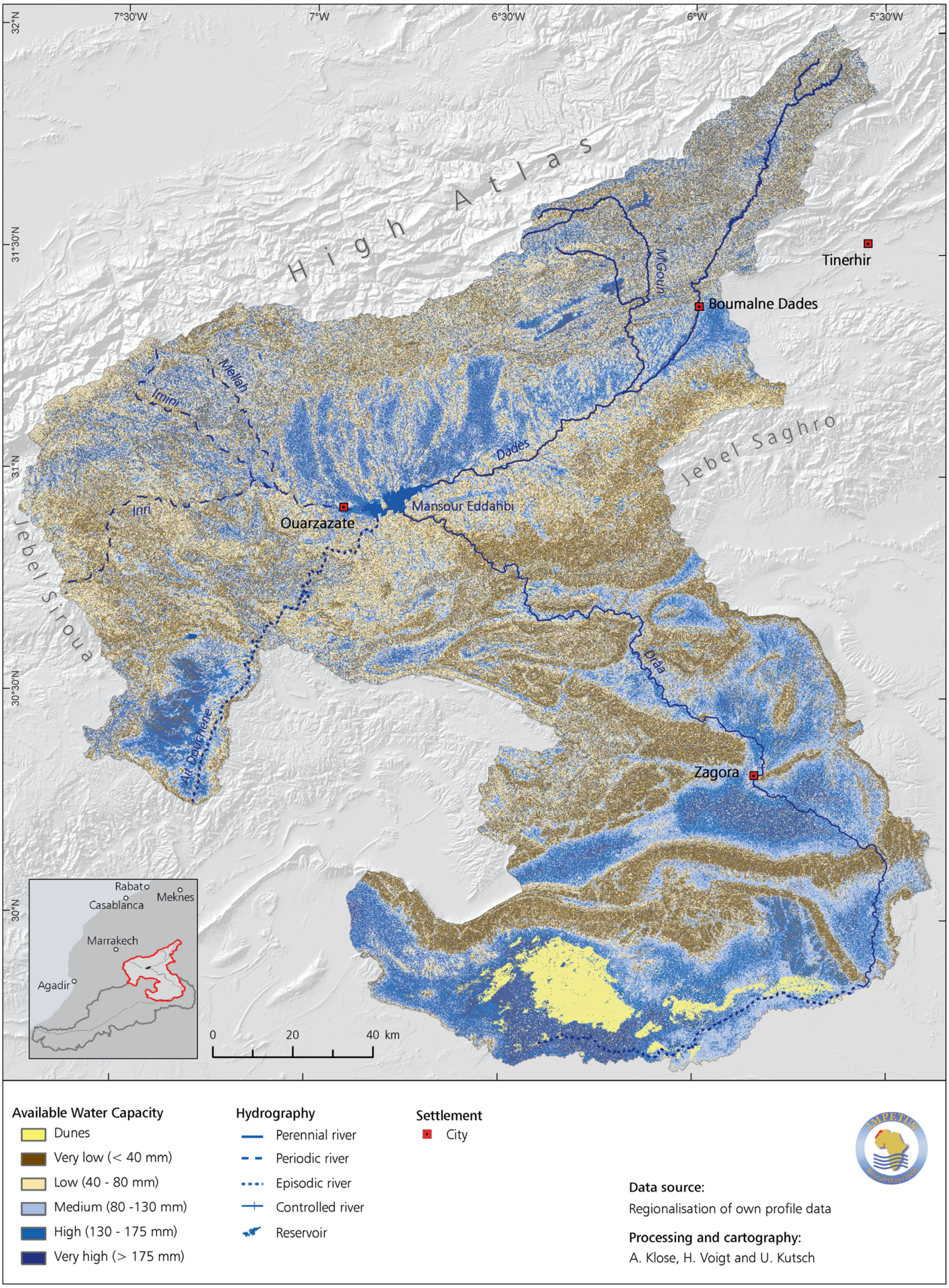

Fig. 3: *Plant available water capacity in the Drâa Catchment*

15

Soil Salinity – A Case Study from Ouled Yaoub

Anna Klose

Soil salinisation is one of the major threats in irrigation agriculture. Irrigation of the date palm oasis along the Oued Drâa depends on water release from the reservoir Mansour Eddahbi. In times of drought, these outlets are irregular and insufficient, so irrigation is done with groundwater of limited quality, leading to an increase in soil salinity. We present the example of the agricultural fields of the village Ouled Yaoub (Oasis of Tinzouline).

Salinity in the Drâa oasis

Soil salinity causes yield losses and can lead to structural instability of the soil if the sodium percentage is high. Whether salts are leached out or accumulated in the soil after irrigation with saline water depends on the amount of irrigation water, the soil properties, the cultivated crops and the drainage. In the Drâa Catchment, the salinity of surface and groundwater, both sources of irrigation water, increases from north to south. Consequently, soil salinity increases, although no simple relationship exists between water and soil quality. The problem seems to be aggravated: soil salinity rose between 1968 and 1980 (Fig. 1).

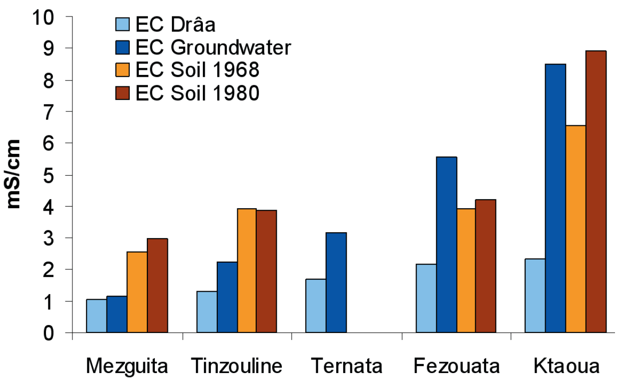

***Fig. 1:** Mean salinity of surface water, groundwater and soil (saturation paste, data for Ternata lacking) in the Drâa oases, given as electric conductivity (EC) (source: Bouidida, 1990).*

Case study Ouled Yaoub

The village of Ouled Yaoub is situated in the southern part of the Oasis of Tinzouline (Fig. 2). This village was chosen as a test site because of its setting upstream a hydrogeological barrier. The agricultural area belonging to Ouled Yaoub is approximately 90 ha in size.

Composite soil samples of 1 ha patches (15–20 samples / ha) were taken from 26 regions and analysed for stone content, texture (Fig. 3), organic carbon (OC), nitrogen and carbonate content, pH, electric conductivity (EC) and ionic composition of the soil water extract (van Reeuwijk, 1995, Tab. 1).

***Tab. 1:** Soil properties in Ouled Yaoub (SD = standard deviation)*

	Mean	SD	Min	Max
stone [%]	0.67	0.63	0.0	2.55
AWC [vol.-%]	16.93	0.95	14.6	18.6
Ks [cm/day]	89.68	90.59	14.1	355.3
OC [%]	0.95	0.21	0.56	1.25
nitrogen [%]	0.08	0.03	0.0	0.11
C/N ratio	12.4	1.39	9.71	16.2
carbonate [%]	8.28	2.07	4.3	11.4
pH	8.2	0.21	8.04	8.57
EC [mS/cm]	5.6	2.11	2.27	11.6
SAR	3.74	0.99	0.92	5.52
ESP	4.07	1.36	0.10	6.44

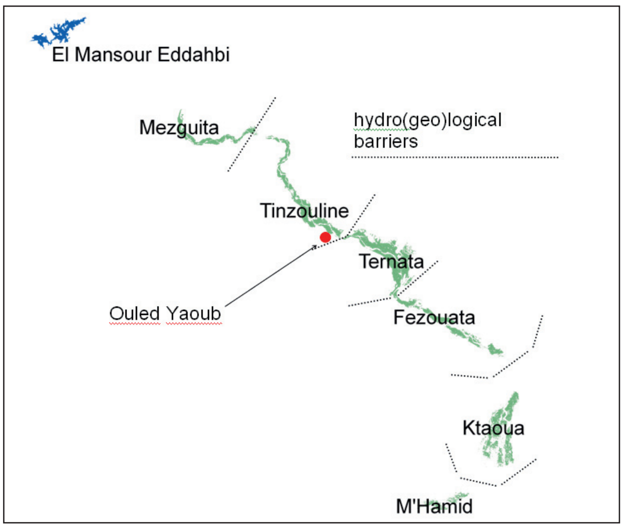

***Fig. 2:** Location of test site Ouled Yaoub.*

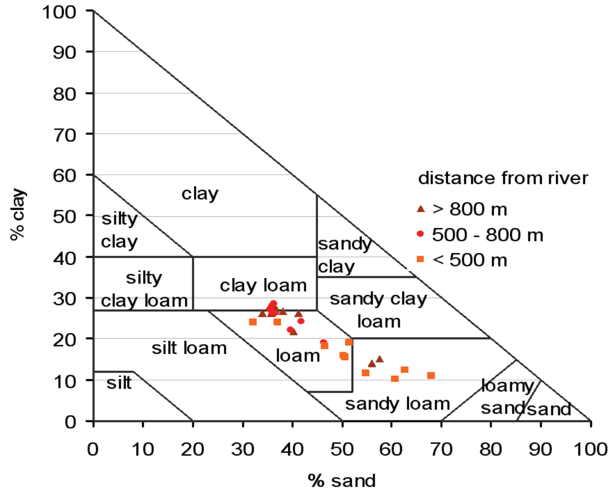

***Fig. 3:** Soil texture in Ouled Yaoub*

Saturated hydraulic conductivity (K_s) and available water capacity (AWC) are derived from pedotransfer functions. Sodium absorption ratio (SAR) and exchangeable sodium percentage (ESP) are measures for sodium saturation (cf. Tab. 1).

The skeleton content is negligible. Due to the loamy texture, the available water capacity is medium to high. Mean K_s can be classified as high, but the standard deviation is also high; values range from medium to very high. Organic carbon and nitrogen contents are generally low, whereas C/N ratios indicate medium to high humus quality. The soils are weakly carbonatic to carbonate-rich. OC, nitrogen and $CaCO_3$ are clearly positively correlated to clay content (r^2 = 0.71; 0.73; 0.61). The clay content first increases with distance to the river; it then reaches

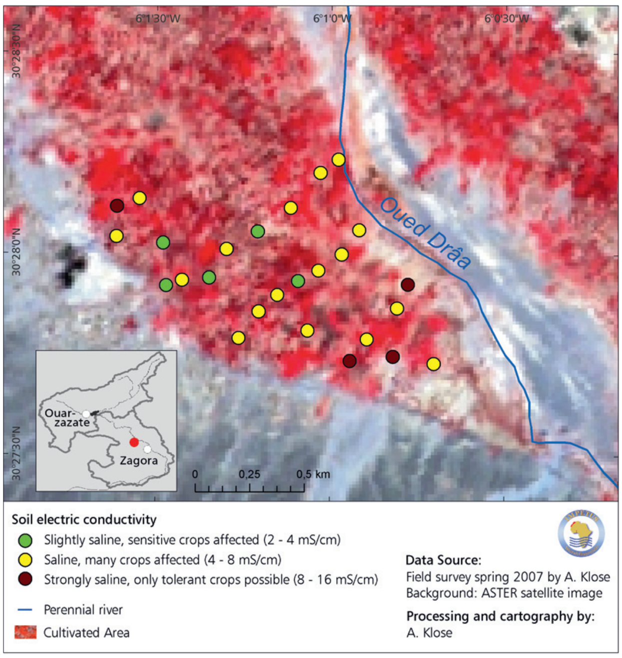

***Fig. 4:** Soil Salinity in Ouled Yaoub*

a maximum at 500–800 m and decreases again at larger distances (Fig. 3, r^2 = 0.62). This pattern, as well as the correlation with nutrients and $CaCO_3$, suggests an oxbow where finer particles are deposited in lower flow velocities and evaporation leaves higher carbonate contents behind. Nevertheless, soil EC values show no clear spatial pattern or correlation to other factors (Fig. 4). Based on the classification of Ritzema (1994), the soils range from slightly to strongly saline. Soils cannot be classified as sodic, as even the maximum ESP and SAR values are considerably below critical limits (Ritzema, 1994). Regarding physical soil properties, the Ouled Yaoub soils can be regarded as suitable for agricultural use. Natural nutrient supply is low, so it is necessary to apply fertilizers. Due to high carbonate contents, crusts may form, restricting rooting. As a consequence of salinity, crops must be at least moderately salt-tolerant (↗ 14, 21, 29, 32).

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16 Soil Erosion Risk in the Drâa Catchment

Anna Klose

Due to high relief energy, overgrazing, sparse vegetation cover and intense precipitation events, the Drâa Catchment is particularly vulnerable to soil erosion. Offsite effects, such as silting of the reservoir Mansour Eddahbi, cause problems for downstream irrigation agriculture. In order to implement efficient anti-erosive measures, it is crucial to determine areas at high risk of erosion. Due to a lack of measurements, erosion risk is assessed with the help of the PESERA model (Pan European Soil Erosion Risk Assessment).

Erosion extent in the Drâa Catchment

The only data on the extent of soil erosion originates from bathymetric surveys of the reservoir Mansour Eddahbi, located near the town of Ouarzazate (↗ 17, 19). The reservoir's catchment is 15,000 km² in size and reaches from the High Atlas to the basin of Ouarzazate. The reservoir has lost 25 % of its capacity in 26 years (1972–1998), corresponding to an erosion rate of 4.6 t/ha/year. Figure 1 shows linear and polynomial extrapolations based on this data up to 2025.

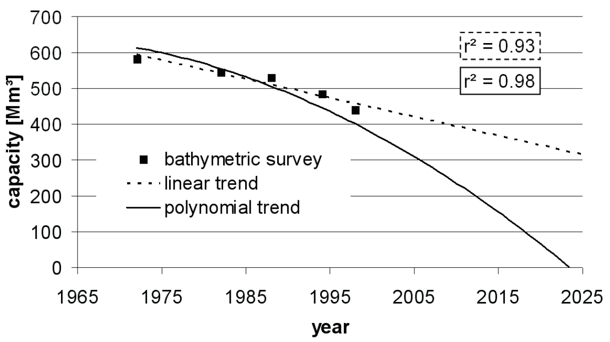

Fig. 1: Bathymetric surveys in the reservoir Mansour Eddahbi and extrapolation to 2025 (data source: DRH)

The difference between the two trends shows their limited capacities for erosion prediction and their lack of information about the spatial distribution of soil erosion.

Modelling approach

The extend and distribution of soil erosion is modeled using PESERA (Pan European Soil Erosion Risk Assessment). The model was developed in the framework of the homonymous project (Kirkby et al., 2004) in order to simulate soil erosion risk for all of Europe. It is a physically-based raster model able to calculate monthly erosion rates (t/ha) in large catchments. It is adapted to semiarid conditions and requires a few commonly available input parameters. Erosion risk is calculated as a function of topography, soil, vegetation and climate (↗ 5, 6, 8, 11, 13, 14).

Model results cannot be directly compared to silting data from the reservoir as PESERA does not account for depositional processes. Thus as a first test, the results are compared to a static model developed for Morocco (Yassin, 1996). These agreed well (weighted kappa coefficient = 0.76), indicating the model's applicability to simulate the processes in the investigated catchment. First PESERA results are given in Fig. 2.

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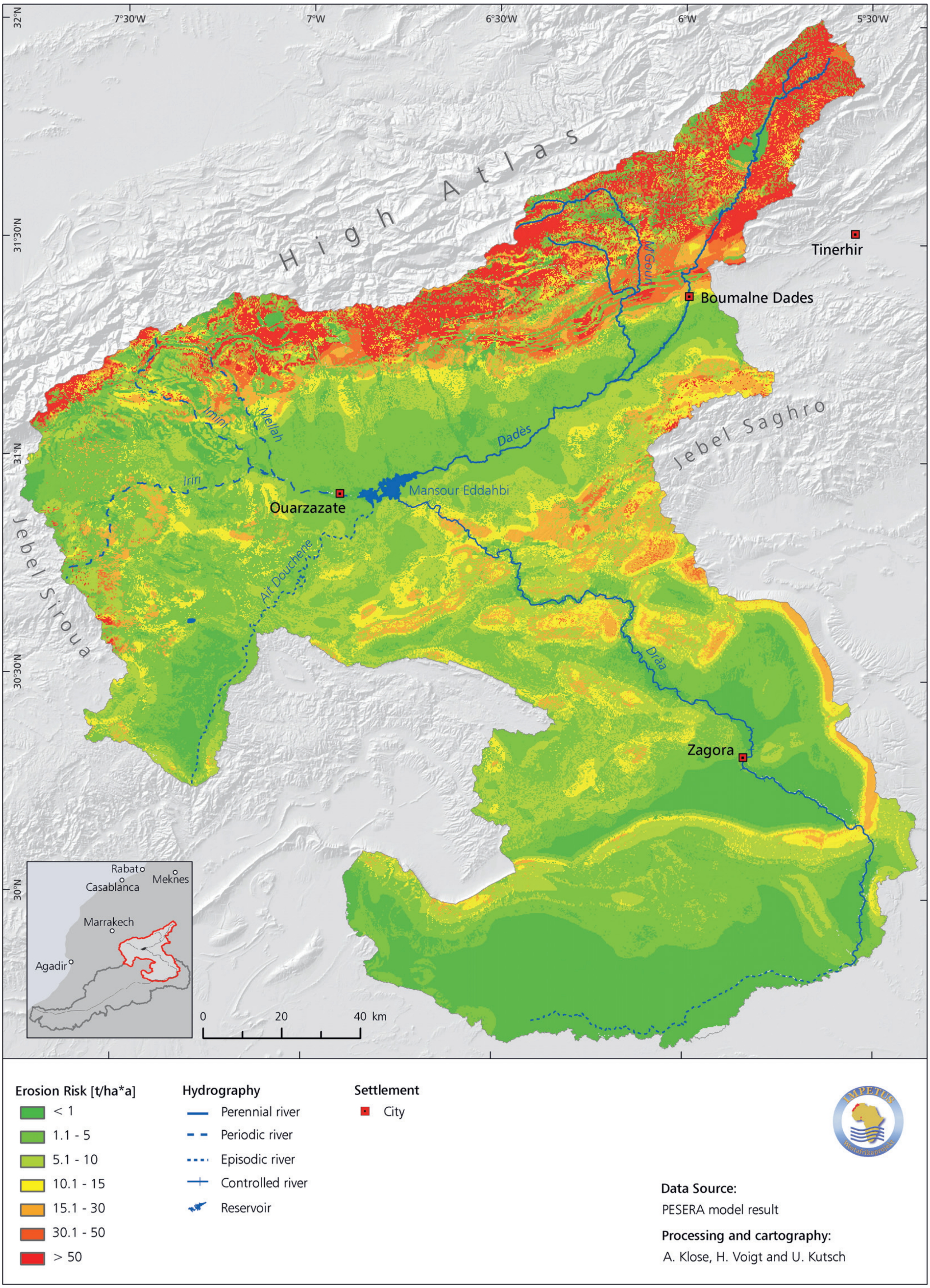

***Fig. 2:** Erosion Risk Assessment in the Drâa Catchment*

The Mansour Eddahbi reservoir near Ouarzazate.

Water Availability

17

Hydrology of the Drâa Basin

Henning Busche

Highly variable precipitation and large evaporation losses cause major water management problems in Morocco. This is especially true for the region south of the High Atlas Mountains, on the border of the Sahara. Water availability depends on different hydrological processes in the mountains and in the basin of Ouarzazate, as well as in the Middle Drâa Valley. Here, the flood-driven natural system has been replaced by a human-controlled flow regime, since the reservoir Mansour-Eddahbi went into service.

High Atlas
High amounts of precipitation (snow and rain) in the High Atlas Mountains are the most reliable source of freshwater in the lowlands, even though about 75 % is lost by evaporation. The only perennial rivers in the research area, M'Goun and Dades, are fed by the karstic aquifers of the north-eastern High Atlas mountain ridge (up to 4071 metres a.s.l.). This aquifer is replenished by melting snow and water infiltrating the highly permeable gravely beds of the tributary channels. With the exclusion of flood events, about 80 % of the runoff eventually infiltrates and reaches the main channel, leading to almost constant baseflow throughout the year (Fig. 1a). In other mountainous rivers, periodic discharge occurs from autumn to spring due to increased storm activity and snow melt, but no considerable baseflow occurs in summer, as the fractured rock does not have the buffering attributes of the karst. During floods, the geology is of minor importance, as surface runoff is the governing process (↗ 8, 18, 19, 20, 23).

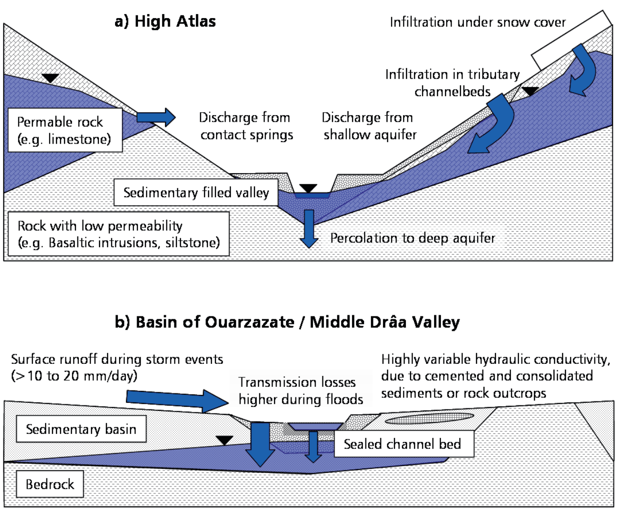

***Fig. 1:** Discharge generating processes in the High Atlas (a) and the Basin of Ouarzazate / Middle Drâa Valley (b).*

Basin of Ouarzazate and Middle Drâa Valley
Baseflow from the High Atlas is routed through the basin of Ouarzazate. Transmission losses are low, as the channel bed is largely naturally sealed. Rare extreme events cause the whole basin and valley to episodically contribute to runoff (Fig. 1b). As the infiltration capacity of the shallow rocky soils is rapidly exceeded during high intensity rainfall, large areas generate surface runoff. In this case, large amounts of water infiltrate the permeable floodplains and the river bed, recharging the groundwater. Before the reservoir was built, runoff frequently reached Lac Iriqui during floods. This is the Drâa's endorheic lake, as the amount of water is not sufficient to overcome the last 750 km to the Atlantic Ocean (Lower Drâa Valley) (↗ 18, 19, 21).

Human-controlled regime
In 1972, the construction of the reservoir Mansour-Eddahbi was finished. Since then, discharge in the Middle Drâa Valley takes place in controlled portions, so-called "lâchers". The reservoir fulfils three objectives:

- Assuring irrigation,
- Generating hydroelectric energy, and
- Reducing flood risks.

Ideally, seven lâchers, 35 million m³ each, are released every year during the growth period. As long as this volume is provided by rainfall, water availability is predictable and water use can be optimised. Most oases have their own small reservoirs, which are filled starting with the reservoir Bounou in the south and ending with the reservoir Agdz in the north. To cover periods between lâchers, groundwater is used for irrigation, using an increasing number of motor pumps. In years of drought, only a little water is released from the reservoir to recharge the oases aquifer systems. Irrigation water is then only taken from wells.

Nowadays, Lac Iriqui is a dry clay pan, as floods seldom reach it (↗ 30, 32, 33).

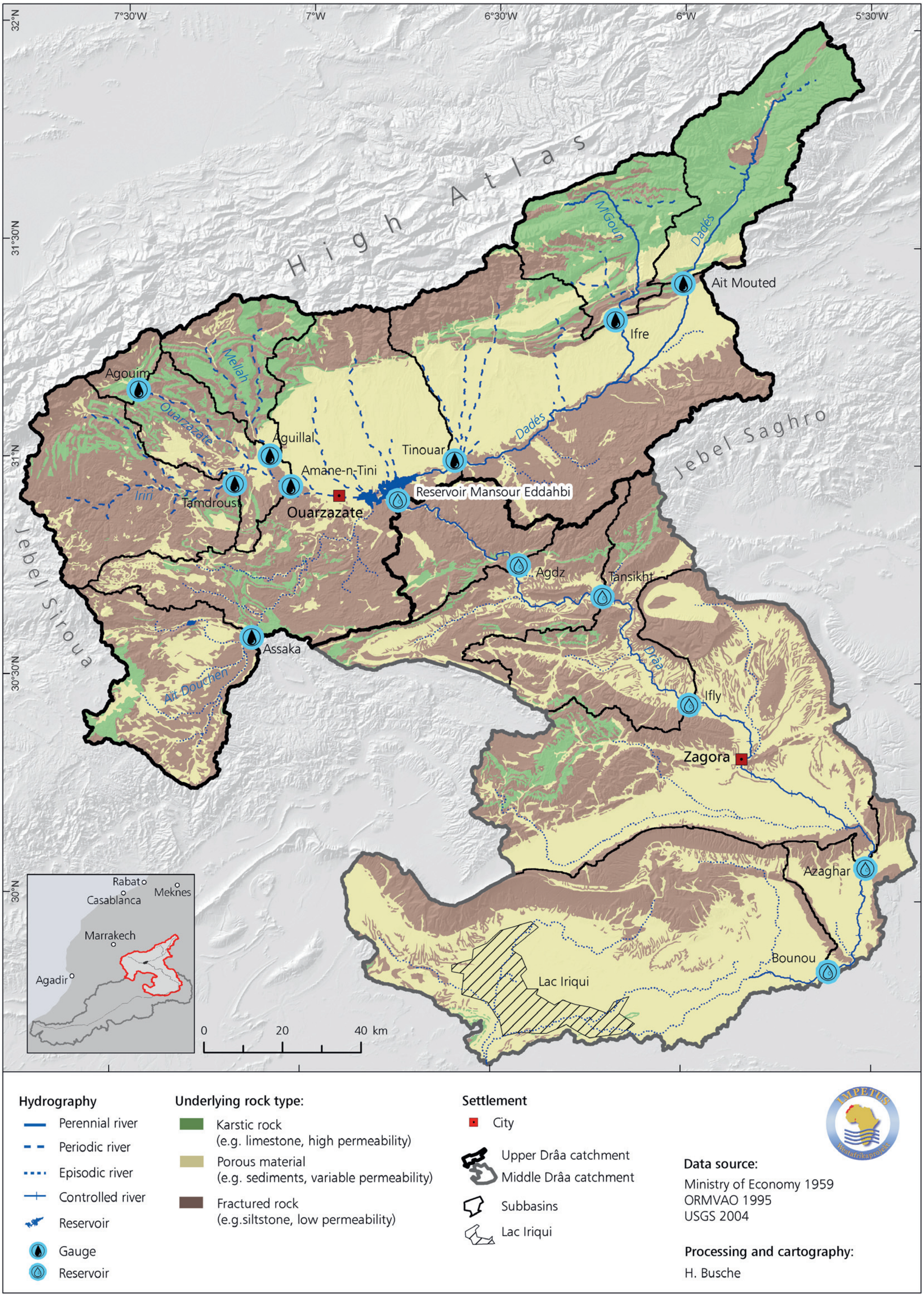

Fig. 2: Hydrography of the Upper and Middle Drâa Basin

18 Hydrogeological Map of the Drâa Basin

Stephan Klose

The hydrogeological map of the Middle Drâa Basin at 1:500,000 provides an overview of major hydrogeological properties of the shallow subsurface. In order to help integrated groundwater management, the data were evaluated and combined in thematic maps, presenting a range of possible hydrogeological parameters.

Hydrogeological information

The hydrogeological map of the Upper and Middle Drâa Basin at 1:500,000 presents hydrogeological information about the shallow subsurface. This map is based on the geological map of Morocco, Sheet Ouarzazate at 1:500,000, which was digitized and interpreted. The geological units are classified in terms of their general geochemical characters, porosities and hydraulic conductivities.

Therefore, hydrogeological attributes are allocated to each stratigraphic unit based on lithologic descriptions taken from the legend of the geological map and own surveys. Thus, the evaluation of the structure of aquifer complexes is adjusted to identical geological units and lithologically similar media. All information is implemented in the GIS ArcView.

Hydrogeological attributes

Various hydrogeological themes can be visualized using their hydrogeological attribution. Porosity and hydraulic conductivity are chosen as major attributes to broadly characterize the aquifer setting. Further single features (e.g. geochemical data) are also available.

All attributes are classified basically according to the hydrogeological map of Germany 1:200,000, which represents a contribution to the International Hydrological Program (IHP) of UNESCO (Url1; Dörhöfer et al., 2001). As a result, the basic geochemical categories are siliceous, carbonatic, sulfatic, halitic and organic.

In order to classify porosity, the common classes like porous, fractured and karstic are used as well as combinations of these categories.

Hydraulic conductivity is attributed by classified K-values. Possible minimum and maximum K-values are assigned based on the range of hydraulic conductivities given by Freeze and Cherry (1979). Classes of hydraulic conductivities are adjusted based on the classification of the hydrogeological map of Germany at 1:200,000 (Url1).

Hydrogeological map

The digital hydrogeological map of the Upper and Middle Drâa Basin at 1:500,000 shows single themes as well as combined screens. A combined screen of porosity and hydraulic conductivity is chosen as the basic map. Regional hydrogeological features can be derived from this map for a first evaluation of groundwater management measures (↗ 17, 20, 21).

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Url1: http://www.bgr.bund.de/cln_011/nn_330804/DE/Themen/Wasser/Projekte/Berat__Info/Huek200/huek200__projektbeschr.html

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Freeze, R. A. and Cherry, J. A. (1979): Groundwater. Prentice Hall, Englewood Cliffs, 604 p.

Tab. 1: Classification of hydraulic conductivity

Class of hydraulic conductivity	K-value [m/s]
Very High	$>10^{-2}$
High	$>10^{-3} – 10^{-2}$
Medium	$>10^{-4} – 10^{-3}$
Moderate	$>10^{-5} – 10^{-4}$
Moderate to low	$>10^{-6} – 10^{-4}$
Low	$>10^{-7} – 10^{-5}$
Very low	$>10^{-9} – 10^{-7}$
Ultralow	$<10^{-9}$
Low to ultralow	$<10^{-5}$
Highly variable	If range of K-values does not fit the classes mentioned above

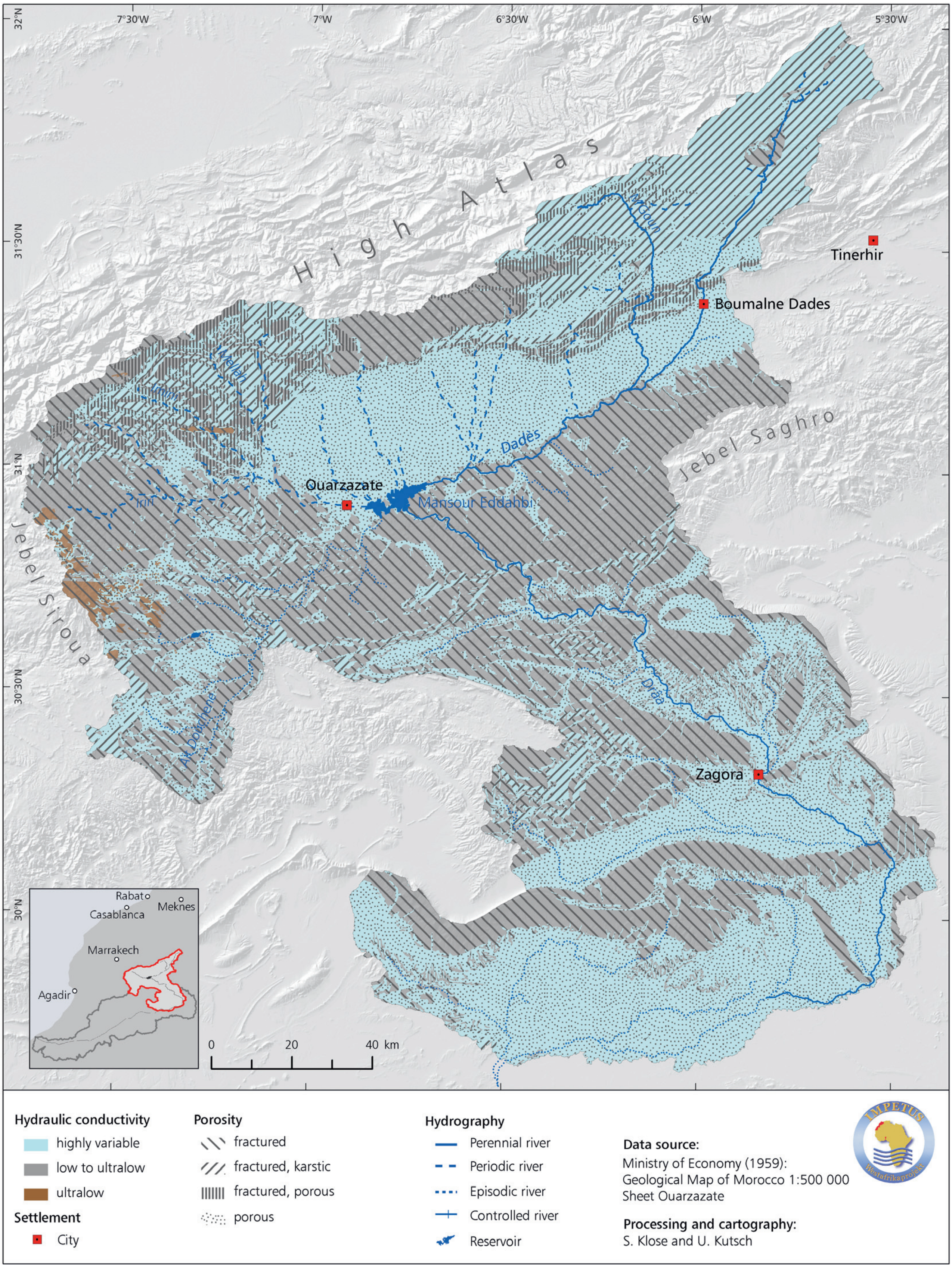


***Fig. 1:** Hydrogeology of the Upper and Middle Drâa Basin*

19 The Reservoir Mansour Eddahbi and its Tributaries

Henning Busche

The Upper Drâa basin experiences the natural hydrological regime of the semi-arid subtropics. Inflow into the reservoir depends on the perennially water-bearing Oued Dades, the periodically water-bearing Oued Ouarzazate and storm runoff from the whole catchment. The underlying runoff-generating processes are different in each case and their importance varies, especially between wet and dry periods.

Discharge generating processes

Approximately 1/4 of the total precipitation in the research area falls in the mountainous region above 2500 metres, which covers about 1/8 of the area. Therefore, discharge generating processes at high altitudes must be addressed carefully. The groundwater driven regime in the elevated north-east of the catchment (gauges Ifre and Ait Mouted) feeds the Oued Dades, the only perennial tributary of the reservoir Mansour Eddahbi (Fig. 3). The reservoir also has periodic tributaries that contribute from autumn to spring, due to seasonally increased storm activity and snowmelt (gauges Tamdroust, Agouillal and Amane-n-Tini). Episodic tributaries (gauge Assaka and the ungauged central basin, as well as the Anti-Atlas) contribute only during extreme flood events (↗ 6, 8, 17, 23).

Sensitivity of discharge

The Basin of Ouarzazate experiences a highly variable precipitation regime. However, variability in annual water yield is nearly twice as high as variability in annual precipitation (Fig 1). This is due to the predominantly high influence of extreme floods with high runoff coefficients. In dry years, extreme floods are rare; then, the perennial baseflow of the Dades is the only discharge that reaches the reservoir.

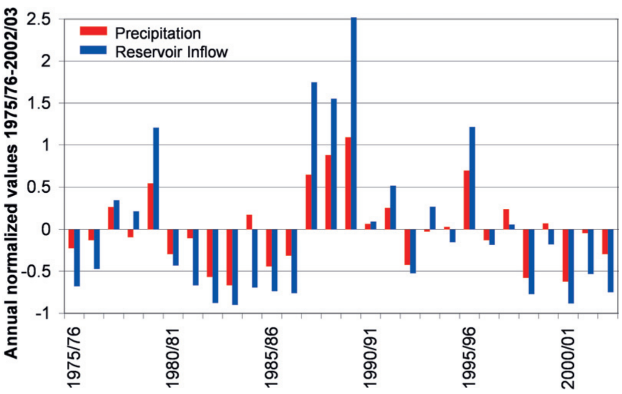


Fig. 1: Normalized inflow into the reservoir Mansour Eddahbi and normalized precipitation in the Basin of Ouarzazate (Stations Ouarzazate, Ifre, Ait Mouted and M'Semrir; Source: Service Eau and ORMVAO, Ouarzazate).

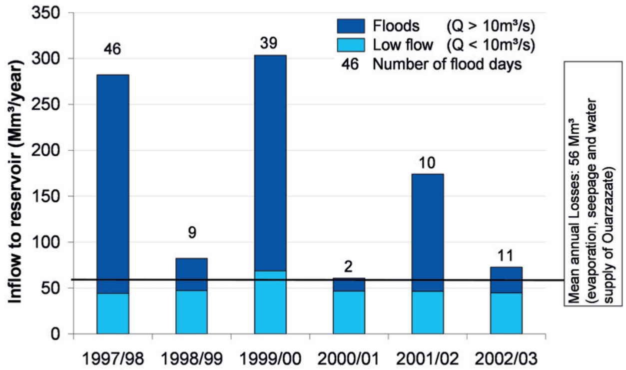


Fig. 2: Annual inflow into the reservoir Mansour Eddahbi and share of floods (Source: ORMVAO).

Baseflow

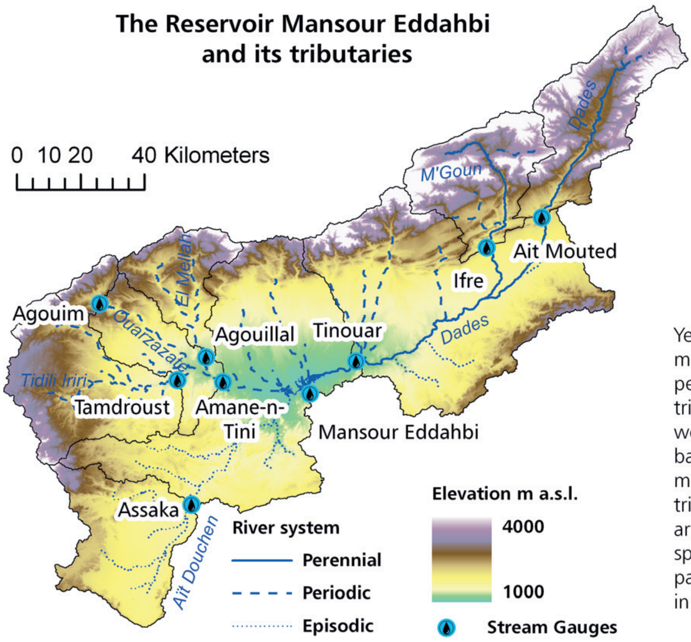
Even in years of drought, the buffered groundwater driven system of the north-eastern regions provides baseflow, providing a reliable base for irrigation in the Dades valley and almost constant inflow of 50 million m³ per year to the reservoir (Fig. 2). This assures that even in years of severe drought the reservoir does not dry up.

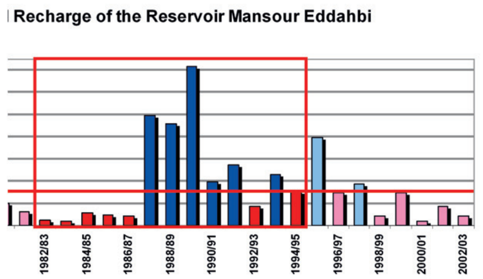
Floods

To ensure irrigation to the oases of the Middle Drâa valley, 245 million m³ of water are needed each year, so that the ideal 7 lâchers (35 million m³ each) can be provided (ORMVAO 1995). Approximately an additional 56 million m³ of water are lost by evaporation, seepage losses, and water supply for the city of Ouarzazate. Flood events are therefore essential to cover the irrigation requirements of the Middle Drâa Valley (↗ 21, 28, 29, 30, 32, 33).

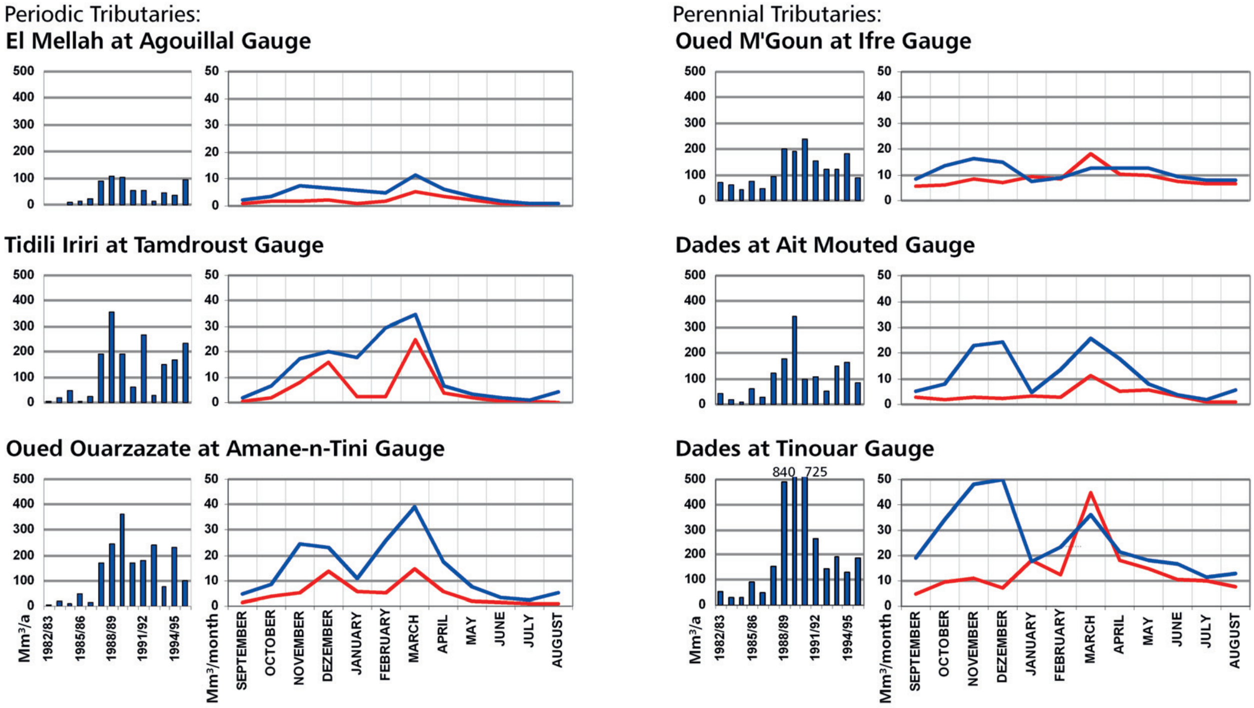
References

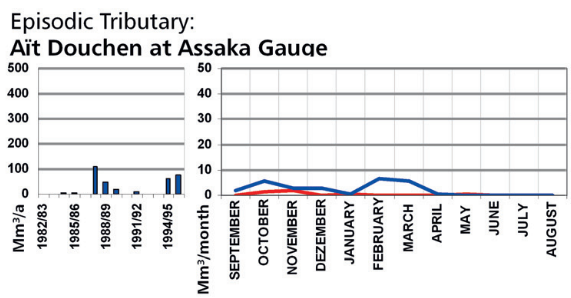
ORMVAO (1995): Etude d'amelioration de l'exploitation des systemes d'irrigation et de drainage de l'ORMVAO. Volume 1, Ouarzazate.





Years in which a recharge of 300 million m³ to the reservoir is not met are considered as dry (red bars), else as wet (blue). For the period 1982-1996 (dark colours) annual discharge of the major tributaries is given below, as well as monthly discharge for dry and wet years separately. The perennial eastern tributaries deliver baseflow throughout the year, though especially wet years are marked by distinct storm activity in autumn. The periodic western tributaries in general deliver little discharge in summer. Wet years are characterized by increased discharge only from autumn to spring. The episodic south-western tributaries (as well as central parts of the basin and parts of the Anti-Atlas) only deliver discharge in some years.





Processing and Cartography:
H. Busche
H. Voigt

Data Source:
ORMVA Ouarzazate
Service Eau Ouarzazate

Fig. 3: *The reservoir Mansour Eddahbi and its tributaries.*

20

Hydrogeology of the Assif-n-Ait Ahmed Catchment

Sébastien Cappy, Stephan Klose, Harald Hoffmann, Volker Osterholt and Simone Bell

The Assif-n-Ait Ahmed watershed is a sub-catchment of the Upper Drâa Basin located in the Central High Atlas Mountains. The distribution of geological units and their hydrogeological features were investigated in order to develop a conceptual hydrogeological model. Furthermore hydrochemistry and isotopes provide insight into the local groundwater flow system.

Catchments characteristics

The Assif-n-Ait Ahmed catchment is located in the Central High Atlas Mountain range southerly adjacent to the ridge of Jbel M'Goun (4,071 m a.s.l.). It covers an area of approximately 110 km², with elevation ranging from 2,000 to 4,071 m a.s.l. The climate is semiarid. Mean annual precipitation varies between 250 and 800 mm depending on the altitude (Schulz, 2006). The Assif-n-Ait Ahmed wadi is fed by numerous small springs, and is a tributary of the M'Goun wadi, which discharges into the Basin of Ouarzazate. The morphology is dominated by extensive scree slopes, debris fans, debris flow channels and deeply incised river beds (De Jong et al., 2004) (↗ 8, 9, 11, 12, 19, 31).

Geological setting

The geological structure of the Assif-n-Ait-Ahmed Catchment is characterized by an east-west trending anticline, which exhibits Triassic rocks overthrust by the Liassic formations of the "Toundoute Nappe" (El Harfi et al., 2001). Partial sandy Triassic schists containing evaporates such as gypsum and halite are found at the base of the slope. Triassic basalts are intercalated and mostly crop out on the slopes. Triassic formations cover around 24 % of the catchment area. A carbonatic sandstone facies occurs locally at the base of the Liassic formations, which consist mainly of limestones and dolomites building up the ridges. The Liassic formations cover approximately 60 % of the catchment area; Quaternary deposits cover the remaining 16 %. Quaternary consolidated sediments can be found as patches of breccias; river beds and debris fans are formed by gravely and sandy sediments.

Detailed geological information is provided by the geological map of the Assif-n-Ait Ahmed Catch-

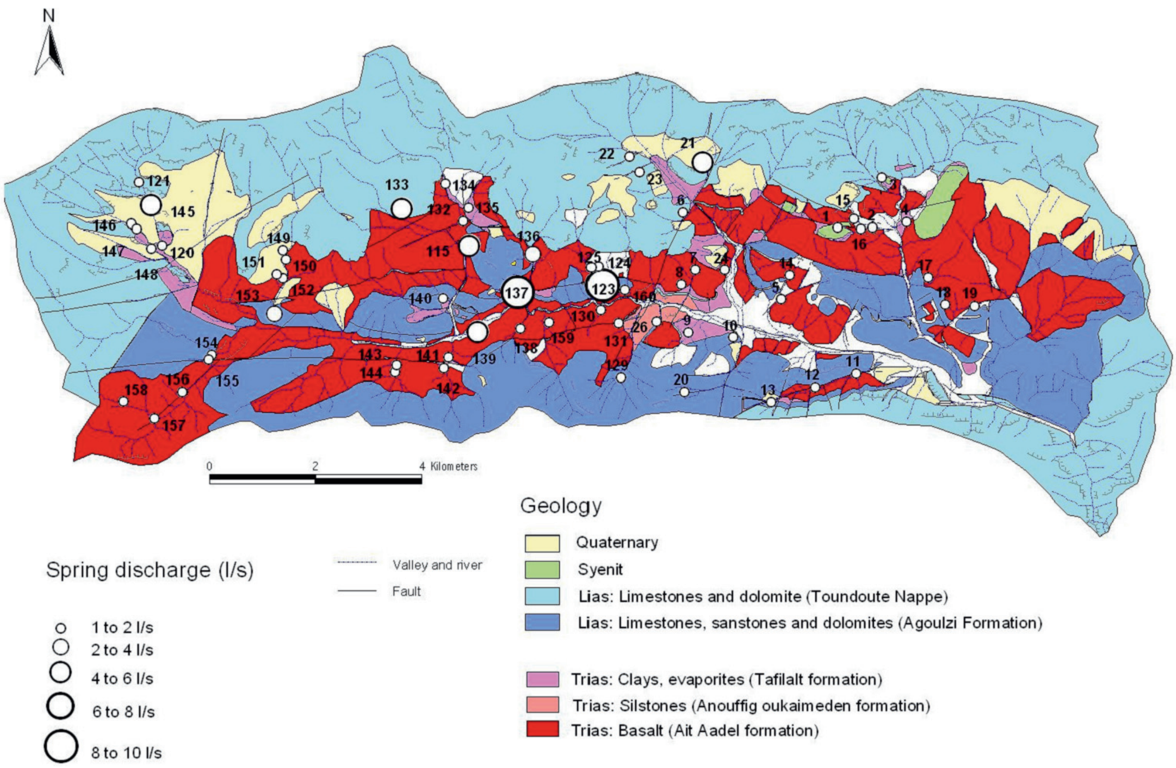


Fig. 1: *Detailed geological map of the Assif-n-Ait Ahmed Catchment with mean spring discharge quantities (Cappy, 2006).*

ment at 1:25,000, based on mapping from various field surveys within the IMPETUS project (Fig. 1).

Hydrogeological setting

In order to define the aquifer structure, hydraulic properties were allocated to the geological units based on general classifications (Freeze and Cherry, 1979) (↗ 17, 18).

Porous Quaternary deposits create a highly permeable aquifer. Fractured and partly karstified Liassic formations have locally varying permeabilities, from low to high (Cappy, 2006). In general, these rocks act as an aquifer. Triassic schists have low to very low permeability and thus are classified as aquitards. Due to different grades of fractioning and density, basalts exhibit low to high permeability and act consequently either as aquitards or aquifers.

Due to the aquifer structure and morphology, most of the groundwater outcrops are contact springs emerging from Liassic aquifers overlying Triassic aquitards and aquicludes.

Conceptual hydrogeological model

Cappy (2006) developed a conceptual hydrogeological model as a result of detailed hydrochemical and isotopic investigations (Fig. 2).

Two major types of spring water were distinguished:

- Low mineralized spring water (Ca-Mg-HCO_3–dominance), draining the Liassic aquifer above 2,400 m a.s.l., with a mean residence time of 4 to 8 years.
- Highly mineralized spring water (Na-Ca-Cl-SO_4-dominance), draining the Liassic aquifer between 2,200 and 2,300 m a.s.l. with mean residence times less than 4 years, but influenced by leaching of evaporates of the Triassic aquitards.

The main altitude of the groundwater recharge area is above 3,200 m a.s.l. for both types of spring water. Because of this, the highly mineralized spring water has a rapid groundwater transition along preferential pathways such as prominent fractures and karst channels (↗ 23).

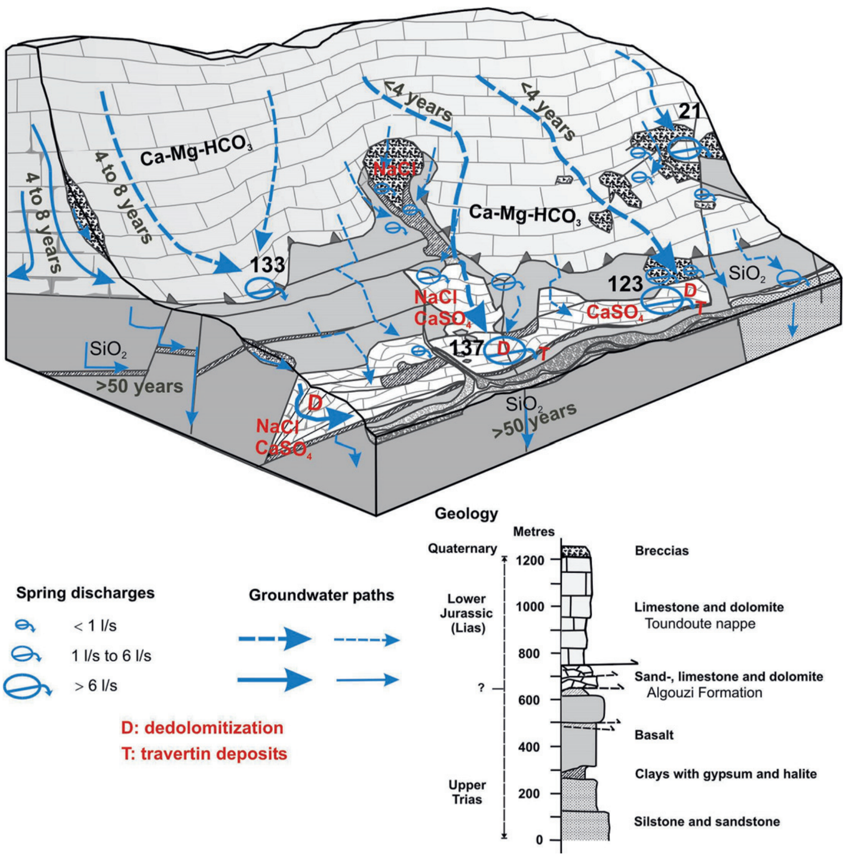


Fig. 2: Conceptual hydrogeological model of the Assif-n-Ait Ahmed Catchment (Cappy, 2006).

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21 Groundwater Quality in Ouled Yaoub

Stephan Klose and Klaus Haaken

Groundwater quality needs to be controlled for drinking water supply and irrigation purposes. Hydrogeological investigations provide insight into the variability of groundwater quality near the village of Ouled Yaoub in the southern part of the oasis of Tinzouline.

Introduction

A hydrochemical characterisation of groundwater was prepared based on two sampling campaigns (November 2005 and March 2007) supported by anthropological studies and pedological and agronomical surveying. 18 water samples were analysed which had been taken from irrigation wells in the oasis and drinking water wells around Ouled Yaoub and furthermore the Oued Drâa. This study focuses solely on inorganic components of the water. The water drinking quality was assessed using the Moroccan standard (Secrétariat d'état charge de l'eau, 2003). The water quality for irrigation purposes was evaluated using the Sodium Absorption Ratio (SAR), Residual Sodium Carbonate (RSC) and Electric Conductivity (EC) as indicators (Ayers and Westcot, 1994, Carrow and Duncan, 1998).

Hydrogeological framework

The research area covers around 10 km² and is located at the south-western margin of the agricultural areas of the oasis Tinzouline along the Oued Drâa. The farmland is underlain by alluvial deposits forming a highly permeable porous aquifer max. 20 m in thickness (source: Service Eau Ouarzazate). Below the alluvial aquifer, fractured siltstones and schists build a fractured aquifer of low permeability. Palaeozoic sedimentary rocks outcropping adjacent to alluvial deposits exhibit generally low permeability but form preferential pathways within highly fractured zones (↗ 18).

Distribution of groundwater types

Two major types of groundwater have been distinguished visualized by Stiff diagrams (Fig. 1). Type A, lateral afflux, originates from the adjacent sedimentary rocks and replenishes the alluvial aquifer with hydrogen-carbonatic dominated water. Type B, oasis water, is found within the alluvial aquifer, and is similar to the surface water of the Oued Drâa but is relatively highly mineralized. The oasis water is classified as sulphate-dominated.

The groundwater composition does not show a clear trend or pattern within the alluvial aquifer, which hints at local influences, such as groundwater salinisation by return flow after flood irrigation.

Quality of drinking water

This evaluation of water quality depends on the inorganic ions whereas the organic content was not analysed. The lateral afflux is relatively low mineralized water of "medium quality" because it contains up to 27 mg/L nitrate. Increased nitrate contents are located in the settlement area, giving a clue about percolation from latrines.

The oasis water is relatively highly mineralized and of "very bad quality" because it contains over 400 mg/L sulphate.

The water of the Oued Drâa is of medium mineral content and classified as "bad quality" because the sulphate content exceeds 250 mg/L.

Quality of irrigation water

The quality of irrigation water was only evaluated at irrigation wells within the oasis. The SAR and adjusted SAR are less than 6 and the RSC has negative values. Thus, the risk of reduced infiltration and water availability for plants by a soil structure break down is negligible. Due to EC of 2080 to 3420 µS/cm of the oasis water, a yield decrease of 20 % is expected for alfalfa. Whereas the growth of weed, barley and date palms is not restricted by the irrigation water quality (↗ 29, 32).

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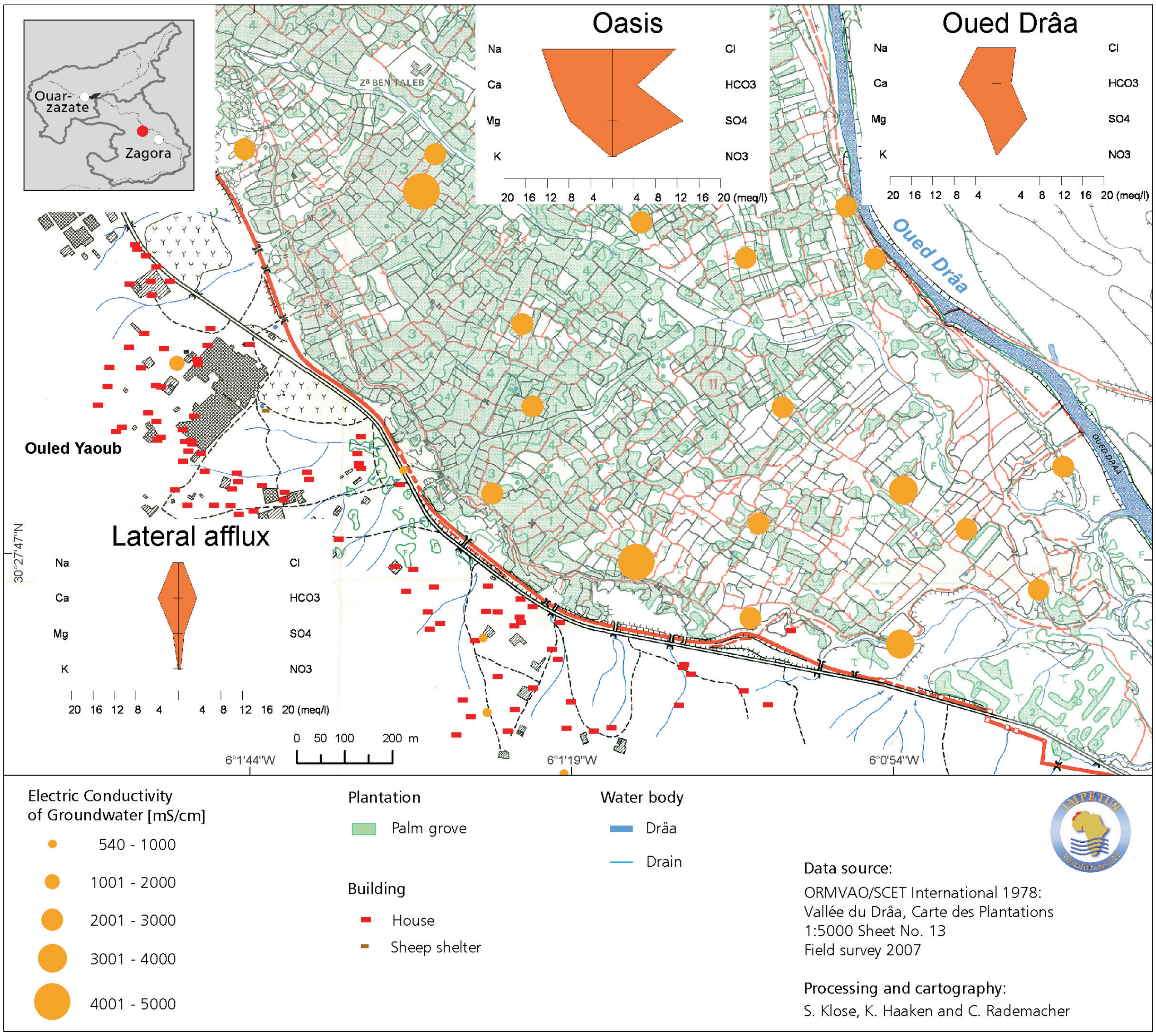

***Fig. 1:** Electric conductivity of groundwater in Ouled Yaoub*

22

Snow Cover Variability in the High Atlas Mountains

Oliver Schulz

The High Atlas is an important water resource for Morocco. Some winter precipitation falls as snow, which serves as a natural water reservoir. In the spring, the melting snow cover feeds rivers and reservoirs of the Upper Drâa Basin.

Introduction

Snow on mountain slopes represents water that is available after snowmelt. Snow cover in the High Atlas Mountains is being affected by climate change, which is already visible in a general shift of climate zones in Morocco. In future climate scenarios, the tendency towards drier and warmer conditions continues. As a consequence, less precipitation is falling as snow, while at the same time, the snow line is rising. Future mountain water delivery to the forelands under a changing climate requires further investigations; for example, changes in the precipitation regime to fewer but more intensive rainfall events could balance the diminishing snow water fraction (↗ 4, 5, 6).

Figure 3 shows the duration of annual snow cover for the Central High Atlas regions belonging to the Drâa Basin in recent years (2001–2006). It provides basic information for a variety of environmental applications (modelling in hydrology, meteorology, and botany).

Methods

For mapping dynamic snow cover, TERRA-MODIS satellite image products were analyzed. With medium spatial resolution (463 m) but high temporal resolution (nominal 1 day), the sensor suits the regional snow cover conditions of several winter snowfall and melt cycles. The classification method Normalized Difference Snow Index NDSI was applied to a time series of 500 images (~100 for each snow cover period 2001–2006, lasting from October/November to May/June). The calculated and mapped values of snow cover indicate a minimum duration, since snow cover between two images was supposed to be uninterrupted if snow was present in both images. Otherwise, snow cover was counted only for the day with recorded snow.

Snow cover variability

As the Upper Drâa Basin extends from 1,050 m (reservoir Mansour Eddahbi) to 4,070 m (Jebel M'Goun) (↗ 11), averaged snow cover duration (2001–2006) varies from less than one day in the lower basin to five months in the M'Goun mountain range (Fig. 1). Differences between the nine sub-basins are related to elevation and time. The western parts of the Upper Drâa Basin (Jebel Siroua, High Atlas) experience more snow at lower elevations than do the eastern parts. In general, the Imini sub basin in the north-western edge near Tichka pass is snowiest at equal elevations.

Temporal variability is expressed in standard deviations for the period 2001–2006, which includes snowy years with more than half a year of snow

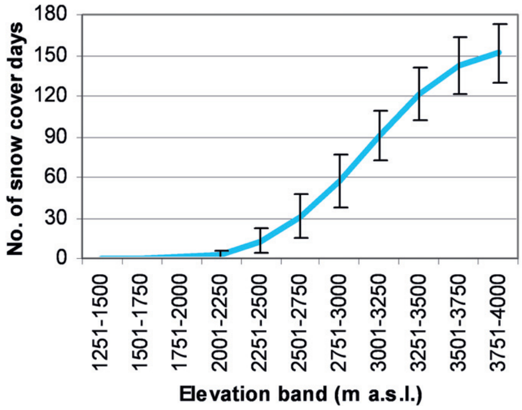

Fig.1: Mean snow cover duration and its temporal standard deviation (2001–2006) in the Upper Drâa Basin (elevation bands of all sub basins).

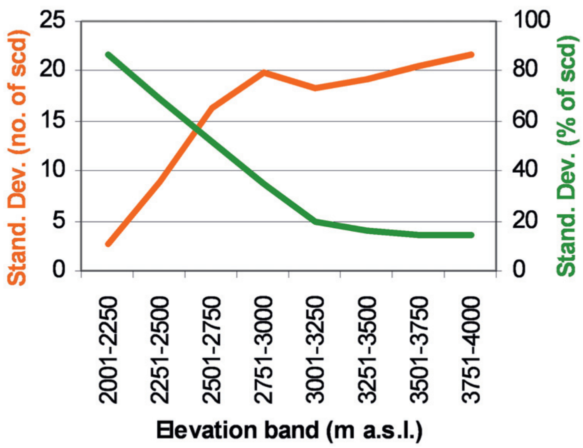

Fig.2: Temporal standard deviation of snow cover duration (2001–2006) in days and in fraction of the snow cover period for the Upper Drâa Basin (elevation bands of all sub basins; scd = snow cover days).

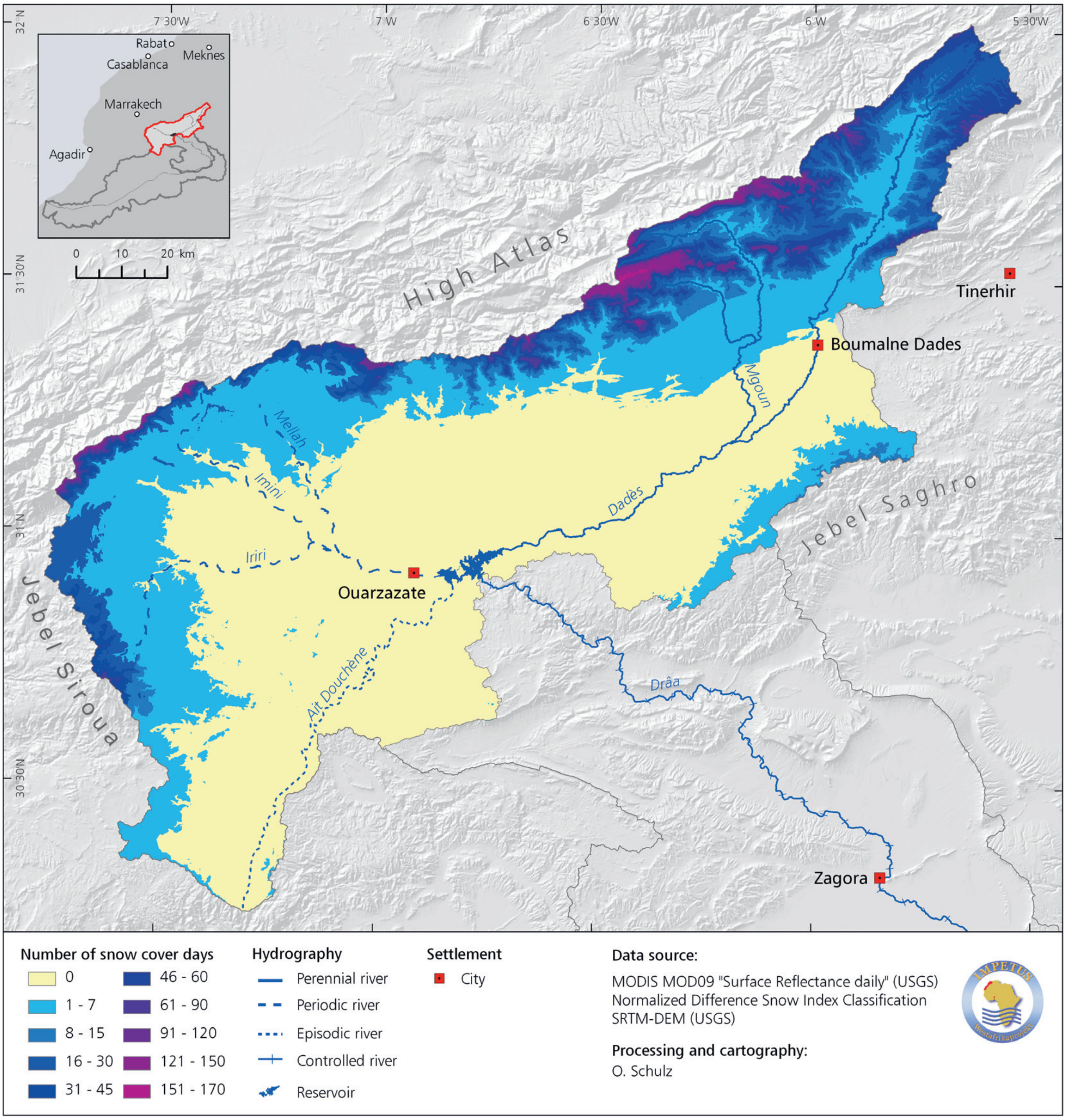

***Fig.3:** Mean snow cover duration for the years 2001–2006 in the Upper Drâa Basin (Central High Atlas Mountains).*

cover in the highest regions (2003/04) and dry years with no snow cover days in the lowlands (2002/03, 2004/05). The annual variability of the number of snow cover days, expressed as a percentage, is highest at lower elevations (green line in Fig. 2). At elevations above 3,000 m, the variability reaches a constant level of 15–20 %. The periods chosen represent slightly too dry to wet winters (rain and snow water equivalent). Therefore, the average snow cover duration in 2001–2006 and its variability is considered representative of the current state of snow cover in the Upper Drâa region (↗ 23).

Data sources

1. TERRA-MODIS satellite images (MOD09 product "Surface Reflectance daily," provided by the United States Geological Survey (USGS) and available free of charge on the internet at http://edcimswww.cr.usgs.gov/pub/imswelcome/
2. SRTM Digital Elevation Model (USGS)

23 Snowmelt Modelling in the High Atlas Mountains

Oliver Schulz

Snow cover in the High Atlas Mountains is an important water resource for irrigation in the Drâa Valley. Since more than half of the precipitation at higher altitudes falls as snow in the Upper Drâa Basin, rainfall-runoff modelling with special emphasis on snowmelt dynamics provides a basis for determining regional water availability.

Introduction

Snow in the High Atlas Mountains is a major source for freshwater renewal and for water availability in the arid lowlands of south-eastern Morocco. Snow accounts for less than 20 % to more than 80 % of total precipitation at the IMPETUS test sites in the M'Goun region (Fig. 1; Schulz and de Jong, 2004; Schulz, 2006) (↗ 7, 8). The snow cover at middle elevations (2,000–3,000 m) is short-lived due to a high melting rate. Above 3000 m, sublimation (evaporation of snow) reduces the water equivalent of snow significantly during winter before snow melt.

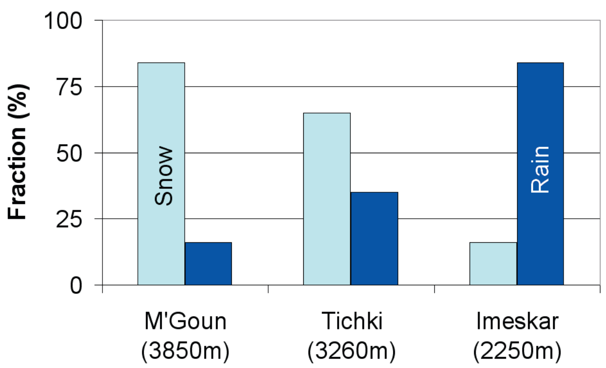

Fig. 1: *Proportions of snow and rain in total precipitation at three IMPETUS stations in the M'Goun region (2001–2005).*

Methods

To cope with this dynamic situation, the snow cover was analyzed in space and time in three ways: remote sensing, ground measurements of snow and weather characteristics, and snowmelt modelling.

At the point scale, I chose the physically based UEB Utah Energy Balance Model (Tarboton and Luce, 1996). This model calculates the local energy balance and considers melt and sublimation in detail. A large number of input data are necessary for the model, provided by measurements at IMPETUS automatic weather stations. At the regional scale, such detailed data are not available. For regional modelling, I applied the conceptual SRM Snowmelt Runoff Model (Martinec, 1975; Martinec et al., 1998) to the mountainous river basin of M'Goun. Based on a simple degree-day approach, daily snow melt in different elevation zones and subsequent river discharge can be calculated from air temperature, precipitation and snow cover distribution.

Snow ablation at the point scale

Sublimation takes place around the world where cold and dry climatic conditions exist. Visible signs of enhanced evaporation are snowy spikes, commonly called penitents. These indicate the initial snow level and seem to rise out of the snow cover while it is carved between the spikes during snow ablation. Snow penitents have been observed at high altitude in the M'Goun range, indicating stable climatic conditions favourable for sublimation during several weeks. Sublimating snow is withdrawn from the local hydrological system, and is usually not considered in water balance estimates.

Physical snow ablation modelling with the UEB model confirms that up to 40 % of the snow water equivalent at high altitudes (>3,000 m) is lost due to sublimation. UEB modelling results have been validated with exemplary snow measurements in the field (snow water equivalent, Fig. 2, and snow surface temperature).

Snow and runoff at the regional scale

Only about 10–20 % of precipitation water from the high mountain areas reaches the reservoir Mansour Eddahbi in the basin of Ouarzazate. The north-eastern tributaries Oued M'Goun and Oued Dadès are the only perennial rivers, and are fed by snow melt and groundwater outflow. Enhanced precipitation and snow melt in the mountains support perennial baseflow into the reservoir. Figure 3 gives the discharge records and modelling results of the SRM for the high mountain sub-basin of the Oued M'Goun in the year 2003/04. Two heavy and three medium precipitation events caused increased discharge, while during the rest of the year, rain and snow-fed groundwater outflow generated a base discharge (↗ 19).

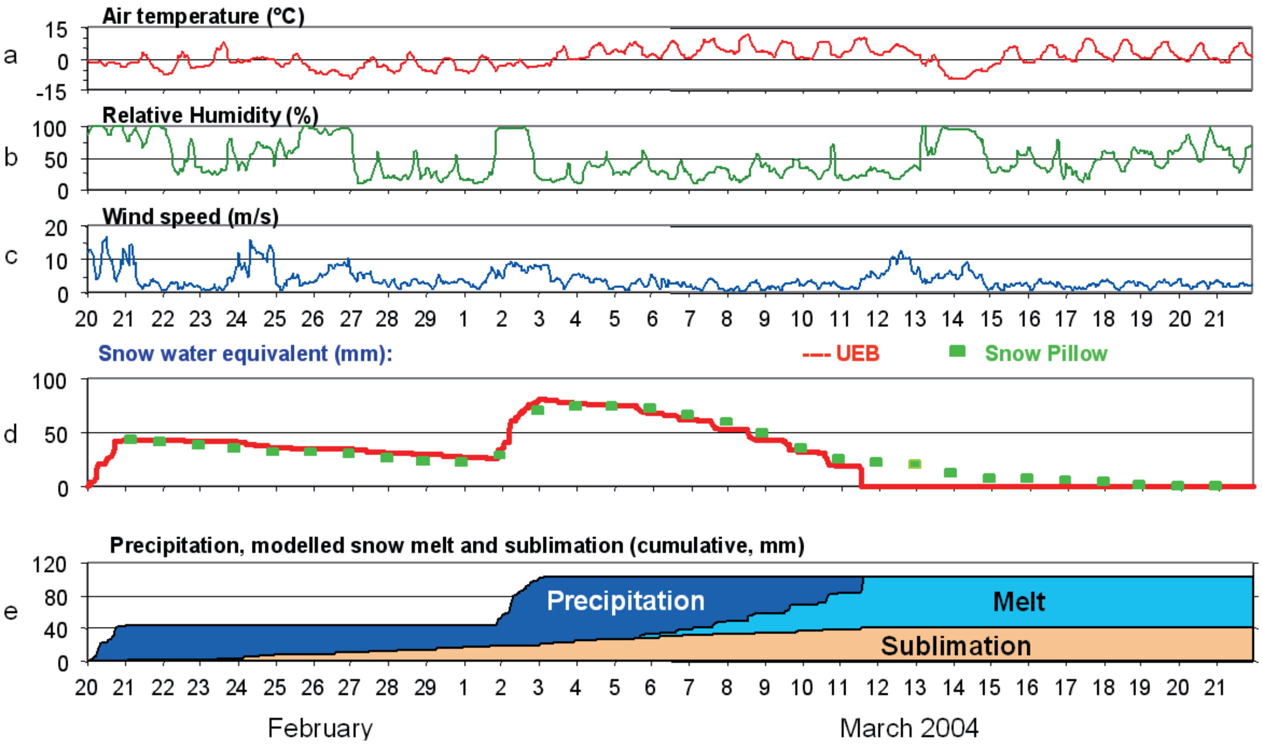

Fig.2: Measurements at the Tounza station (a, b, c: weather data from the automatic weather station, d: snow water equivalent calculated from snow weight on a snow pillow) and e: UEB-modelled snow ablation processes (melt and sublimation; precipitation was measured).

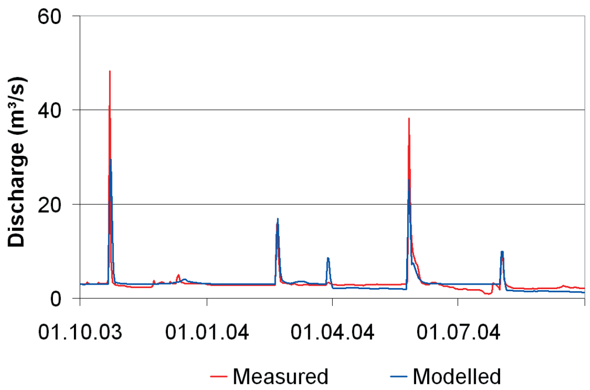

Fig. 3: Measured discharge at the stream gauge Ifre (M'Goun catchment) and SRM-modelling results (data source: Service Eau de Ouarzazate, IMPETUS).

Conclusions

Detailed physical modelling (UEB) improves our understanding of the interaction of snow ablation processes in high mountain areas and supports parameterisation in the more conceptual regional modelling with SRM. The results of snow cover monitoring as well as rainfall-runoff and snowmelt modelling highlight the importance of a few heavy rain- and snowfall events for efficient water delivery to the reservoir. Apart from water losses through high evaporation rates and periods of snow sublimation in winter, this study confirms that during most of the year, discharge is generated by groundwater outflow. Only heavy events produce floods and refill the Mansour Eddahbi reservoir near Ouarzazate. In contrast, the base flow of perennial rivers only balances water losses through lake evaporation and drinking water consumption (↗ 17, 19).

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Castle of Telouat near Tichka pass, Central High Atlas Mountains.

Population, Land Use and Livelihood Security

24 Current Development of the Population in the Provinces of Ouarzazate and Zagora

Stephan Platt

The development of the population in the catchment area of the Drâa, represented by the provinces of Ouarzazate, and Zagora, stands in mutual relationship with water consumption and water availability in this region. The provinces play a marginalized role at economic, infrastructural and social level within the Kingdom of Morocco.

Aridity and demography

In the past few decades, recurring periods of aridity have damaged the agriculturally based economy of the region. In addition to the increasingly scarce amounts of available irrigation water, the quantity and quality of domestic water has decreased. Apart from the indirect economic consequences, e.g., increasing labor migration, the direct negative impacts of the water crisis can be seen in the areas of nutrition, hygiene, reproductive health, and quality of life. Migration and malnutrition, therefore, both critically influence the response indicators of demographic development: urbanization, age structure, fertility- and mortality rates (Fig. 1; ↗ 3, 6, 17, 21, 25, 26, 28, 30, 32, 33).

When undertaking a sociological analysis of how water and land use affect the living conditions in the catchment area of the Drâa, it is important to examine population dynamics, because population dynamics constitute both economic and socio-cultural indicators of social change and they exert influence upon the future development of the region.

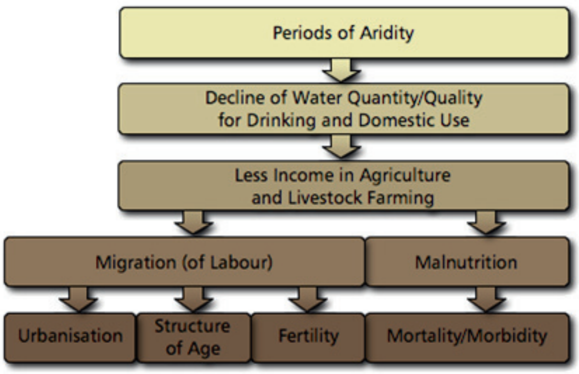

***Fig. 1:** Interrelations between periods of aridity and demographic factors.*

Population and progress

The largely rural provinces of Ouarzazate, and Zagora are, compared with the prospering regions in the northwest of Morocco, generally characterized by low population density, young populations, high reproduction rates and large postnatal mortality rates.

The increase in the population size in the catchment area of the Drâa can be analysed on the basis of the national census data of 1994 and 2004 (Fig. 2). The spatial distribution of population growth is highly heterogeneous. In some areas, population growth even reaches a negative value. In addition to being caused by national and international migration, this negative population growth results from regional migration movements; people migrate from the most marginalized regions to the increasingly urbanized communes along the Drâa and the Dadès rivers. These regions offer income alternatives, particularly in the tourism sector, to subsistence agriculture.

The most important spot for regional economic development, moreover, is the urban agglomeration of Ouarzazate and Tabount, which possessed an annual population growth of 3.3 % between 1994 and 2004. The 74,600 inhabitants in 2004 constituted 15 % percent of the province of Ouarzazate's total population. In addition to a strong tourism sector, the film industry - Ouarzazate being one of the most developed cities in this economic branch on the entire continent of Africa - plays a crucial role in providing employment.

Data sources

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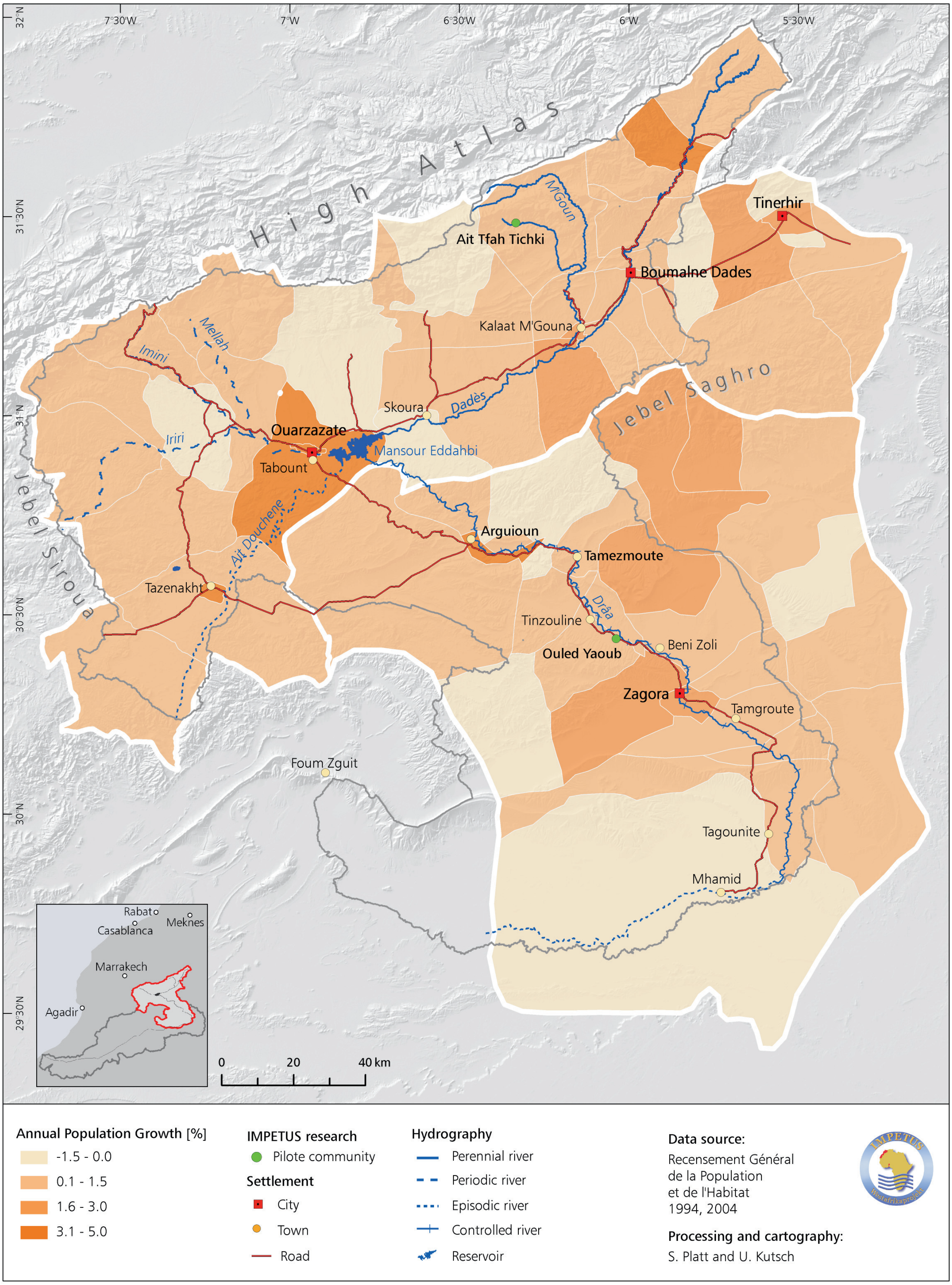

***Fig. 2:** Annual population growth 1994-2004 in the communes of the provinces of Ouarzazate and Zagora.*

25

Development of the Urbanized Regions in the Provinces of Ouarzazate and Zagora until 2020

Stephan Platt

Intensified emigration from marginalized, rural communes into urban centres is currently the most important demographic phenomenon in the provinces of Ouarzazate and Zagora. Searching for alternative income opportunities to subsistence agriculture, people not only migrate nationally and internationally, but also - intra-regionally. Migration and urbanisation trends are therefore both important indicators of water scarcity and significantly affect the regions development.

Urbanisation and migration

The demographic dynamics of a society are determined by numerous interdependent factors (Fig. 1). Urbanisation and migration influence the fertility and the age structures of society by modifying reproductive behaviour. (↗ 3, 24, 26)

Apart from (a circular working-) migration towards the thriving urban agglomerations of the north, regional migration movements are most common. Consequently, there is an increasing urbanisation of the already urbanized communities in the provinces Ouarzazate and Zagora. Pushing factors for migration are scarce water resources and poor economic and infrastructure bases. Pulling factors for migration are diversified economic possibilities and better education and supply infrastructures, which are to be found in urban centres.

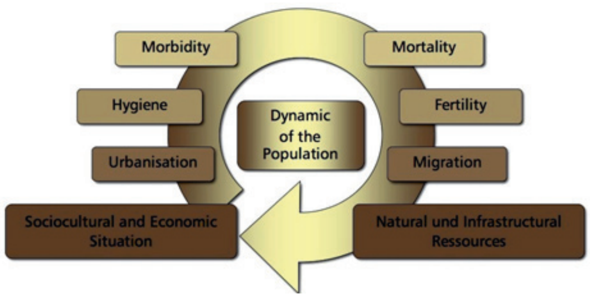

***Fig. 1:** Important factors, which affect the dynamic of a population reciprocally.*

Urbanized regions along the rivers

The numeric model SPECTRUM/Demproj uses quantitative data concerning migration, fertility, mortality, age structure, and urbanisation to determine the future development of a population (Fig. 2).

Because the urban centres grow much faster (3.1 % average annual growth) than do rural areas (0.8 % average annual growth), the urbanized areas of the region play a crucial role in the region's demographic development.

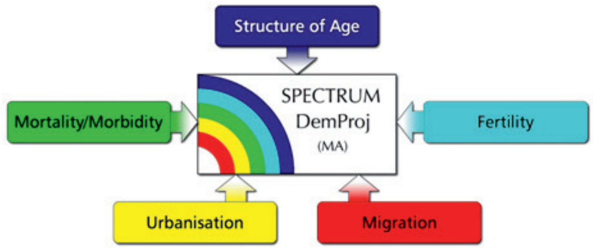

***Fig. 2:** Variables of SPECTRUM/DemProj*

The future size of the population of the regional urban agglomerations in the catchment area of the Drâa was projected into the year 2020 on the basis of the 2004 national census data (Fig. 3). The census listed a total of nine urban agglomerations. In 2004, the population dimensions ranged from 2,800 inhabitants in Skoura, to 53,500 inhabitants in Ouarzazate. The 187,800 inhabitants represented 24.1 % of the whole population in the provinces of Ouarzazate and Zagora. The four urban areas, Ouarzazate, Tabount, Zagora, and Tinerhir, contain 77.6 % of the urban population and 18.7 % of the whole population in the two provinces. Regarding the close projection goal for the year 2020, few significant changes in the population trend are expected. This is because demographic processes react slowly to changes in initial parameters. A disproportional population growth, therefore, is not to be expected in the near future.

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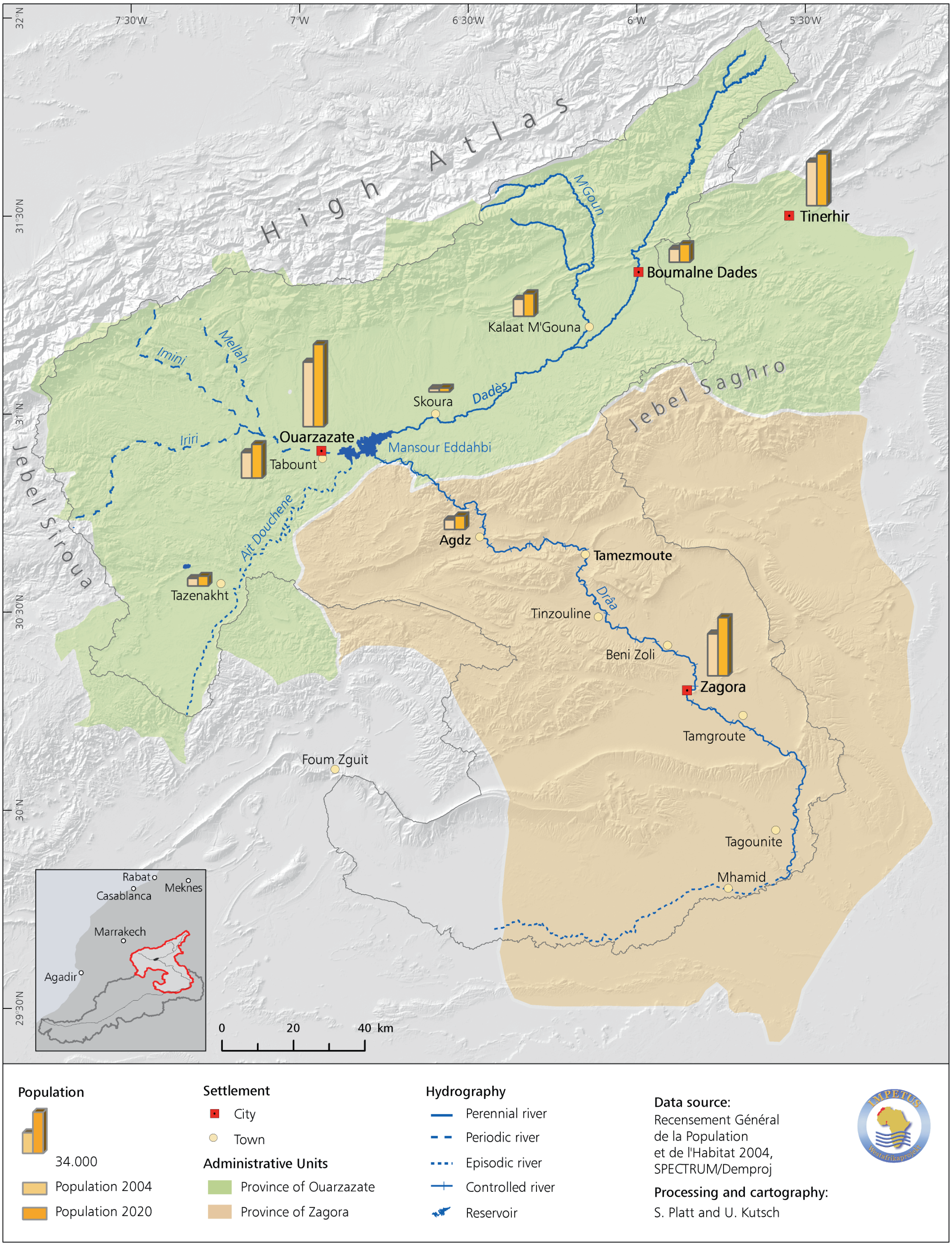

Fig. 3: Population 2004 and 2020 of the urbanized regions in the Drâa Catchment.

26 Work Destinations of Ouled Yaoub Labour Migrants

Christina Rademacher

The Drâa Valley is part of the Moroccan migration belt. The region, agriculturally-dominated, marginalised, and possessing little industry apart from tourism, is "exporting" predominantly male workers to other parts of the country. A small percentage of its workers also migrate internationally. Most migrants work in construction as unskilled labourers. The primary goal of these migrant workers is to support their families, who remain in the villages.

Introduction

The subject of this investigation is the causes and effects of labour migration upon the socio-economic setting, particularly with reference to the different ethnic groups of Ouled Yaoub, a village of 1,000 inhabitants situated 30 km north of Zagora. Based upon this paper's own data, the local development of labour migration, including job situation, work destinations, and some new trends are presented. (↗ 2, 3, 32, 33)

Methods

During long-term fieldwork (2002–2006), in addition to interviews with local experts, qualitative interviews were conducted with migrants and their families in the village as well as in different cities. Furthermore, quantitative surveys on the development of migration were also taken. Survey results have also been compared with interview statements.

Development of migration

Labour migration from the Drâa Valley to Moroccan towns and to foreign countries has become the most important income strategy since Morocco's independence in 1956. This is both because agriculture alone cannot generate sufficient income and because of the scarcity of other job opportunities. What began with young, unmarried men leaving the village seasonally to find work, primarily in construction jobs throughout Morocco, has become a strategy employed by all age groups. Youth as young as thirteen or fourteen all the way up to married men in their sixties migrate for the purpose of ensuring the survival of their families who remain in the village. These men continue as labour migrants throughout the entirety of their working lives. Survey data shows that 57 % of the migrants found work in construction, 12 % in the service sector, and the rest in diversified fields. Most of these migrants were paid modestly (1,250–1,500 DH/month). Only 3 % of migrants found work as civil servants, obtaining a regular and comparatively high salary. The low wages of the majority of migrants is rooted in the poor educational background of most migrants. Even today, dropping out after five or six years of elementary school is common.

According to migrants, the high cost of living in the city prevents most of them from relocating their families to the city. In addition, socio-familial pressures oblige sons to care for their aged parents financially, but most of them are not capable of financing two households. As a result, most families split up.

How has the labour migration of the Drâa Valley changed from Morocco's independence until today?

Since the 1960s, labour migration has been the most important income strategy for all ethnic groups (Fig. 1).

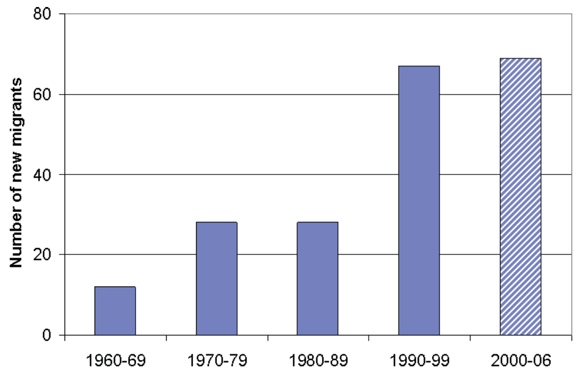

***Fig. 1:** Initial migration per decade in Ouled Yaoub. Data source: Surveys 2004/05 and 2006.*

While seasonal labour migration of a small proportion of the village's young men was viewed with suspicion by locales during the 1960's, this practice became common as the village's socio-economic situation weakened. Consequently, in the past decades migration has become a type of ritual, a "rite of passage", for young males entering into manhood. The age at which a youth first migrates-whether for labour or for education-depends upon the socio-economic situation of his family, the value his family places upon education, and upon the personal aspirations of the youth.

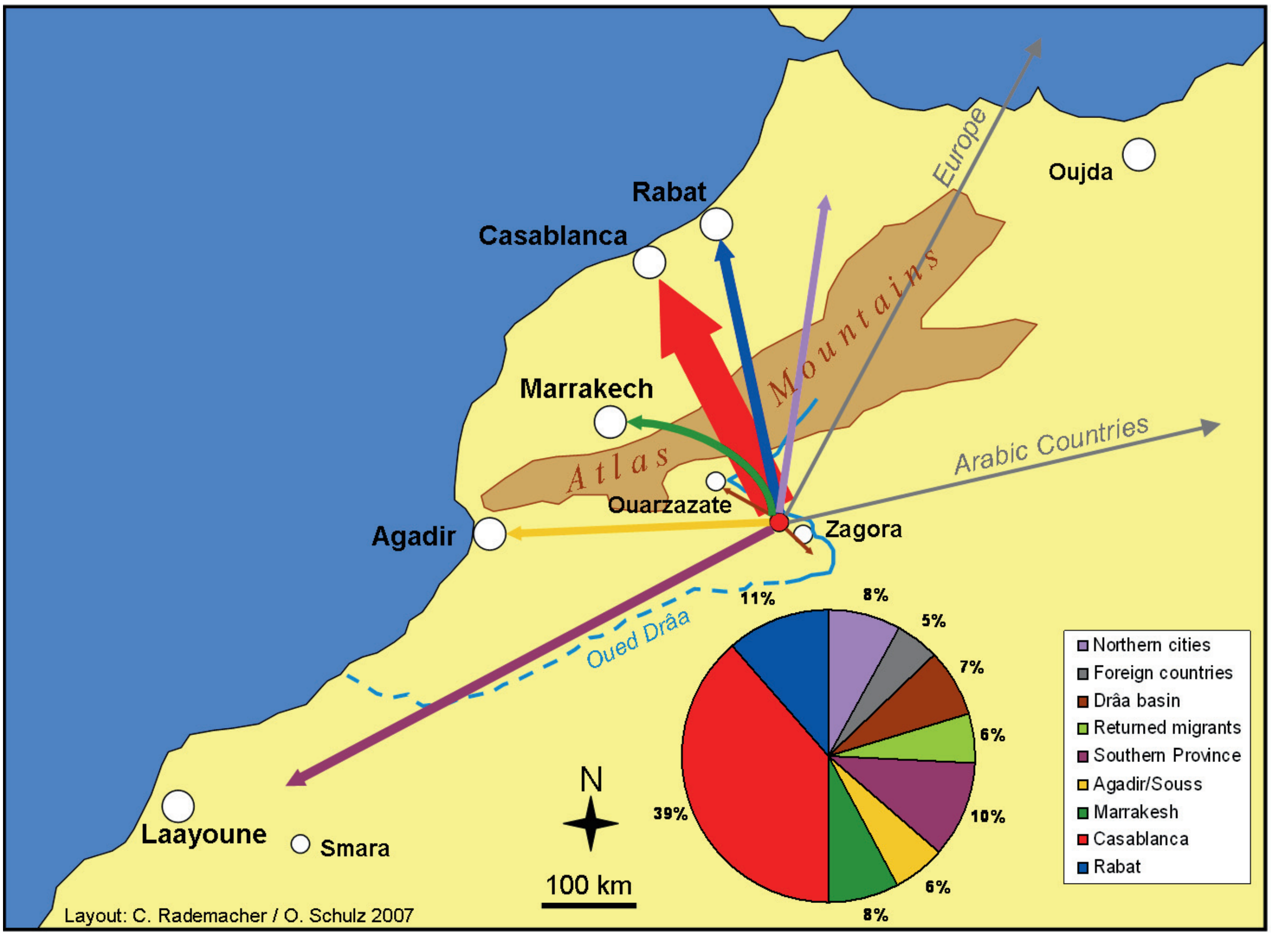

Fig. 2: Destinations of Ouled Yaoub's labor migrants (2004).

Work destinations of migrants
Most migrants who work on construction sites are highly mobile individuals and follow job opportunities across the country. Consequently, the information given in the map from March 2004 is highly variable, reflecting the various situations of the economic centres of the country (Fig. 2).

From the 1980's and 1990's onwards, increasing numbers of Ouled Yaoub migrants travelled to the Southern Province to seek work. This preference for the Southern Province stemmed both from the lower cost of living in the South as well as from the South's booming construction sector. This trend has changed over the past few years. Today, good job opportunities are rare. For example, in 2006, sixteen out of the twenty migrants went to northern cities such as Casablanca, Rabat, and Marrakech, while only one migrant found work in Smara.

International migration from Ouled Yaoub is low (5 %), with some European countries, Saudi-Arabia, and Libya being the primary destinations.

A new trend, beginning around the turn of the century is the migration of entire families. Living together as a family, even under a city's difficult economic conditions, seems to be preferred both to being separated and to investing in the non-profitable agriculture of the Drâa Valley. Since 2000, some 15 nuclear families have left the village.

27

Drought Effects on Livestock Husbandry

Claudia Heidecke and Andreas Roth

Livestock husbandry is an important income source for families in the Drâa region. The number of animals is hard to measure and varies over the years and from north to south. During drought years, the number of animals is reduced due to fodder shortages.

Introduction

Livestock in the Drâa region consist primarily of goats and sheep, and rarely cattle. Most farmers also keep a donkey for transportation of goods, or dromedaries in the southern oasis. Besides livestock as an income source, they are kept for food supply, hedging and prestige. The numbers of livestock vary regionally and temporally. This part provides an overview and analyses of available data and a comparison with IMPETUS survey data from 2005. Furthermore, the effect of drought on the number of animals is analysed.

Livestock in the Drâa region

Figure 3 illustrates the number of cattle, sheep, goats and dromedaries per ha on the communal level in the Drâa region. The data was calculated from the most recent agricultural census, from 1996. In the mountainous areas in the north, the number of animals per ha is much higher than in the south due to more fodder and water availability in the High Atlas Mountains and therefore more transhumance. In the Middle Drâa Valley, transhumance is restricted and most farmers keep animals on a farm. There are many more sheep and goats than cattle as cattle are more expensive to keep and need more fodder.

In 2005, after a long drought period, a farm survey was carried out by IMPETUS in the Middle Drâa and Dades Valleys with a sample of 280 farmers. Figure 1 shows the number of animals (in 2000 and 2005) per farmer interviewed. The sample, however, only groups animals that are kept on a farm and does not include transhumance. Due to dry years in this period, a lot of animals were lost or sold mainly due to fodder shortage, illness or auto consumption. In the Middle Drâa Valley, the decrease is greater for all animals as precipitation and hence fodder availability is weaker in the area. The number of mules per farmer is stable as mules are important for transportation and for work in the fields.

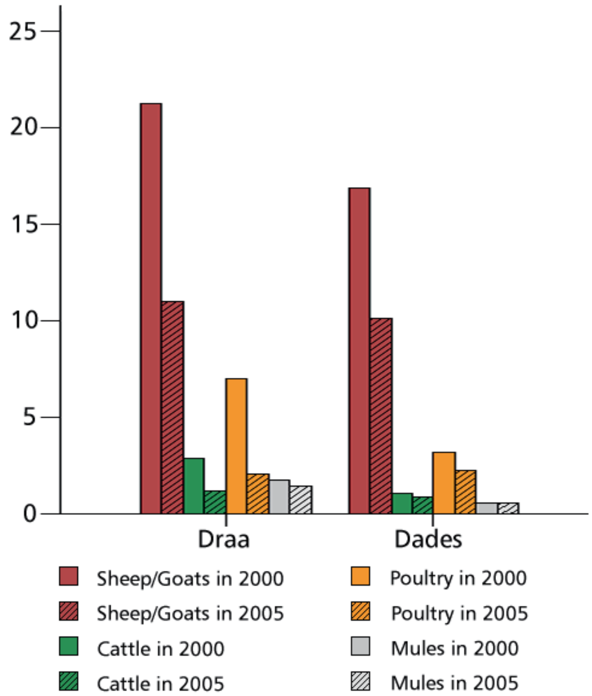

Fig. 1: *Number of animals per farmer in 2000 and 2005.*

Drought effects on livestock

Figure 2 is closely related to Fig. 1, and illustrates the relationship between water and livestock. This figure shows the number of goats, sheep and cattle kept between 1980 and 2003 in the region as well as the annual precipitation in mm. The number of animals fluctuates due to varying forage availability as a result of precipitation variability. This is mainly due to the latent water stress of plants. Precipitation tends to trigger the development of important herbaceous plants such as grasses, causing an increase in the number of animals. Since the mid 90's, the number of goats and sheep declined constantly due to the continuing drought. The number of cattle also declined. As cattle are not used, in transhumance they do not vary to the same extent as sheep or goats (↗ 17, 19, 28, 31).

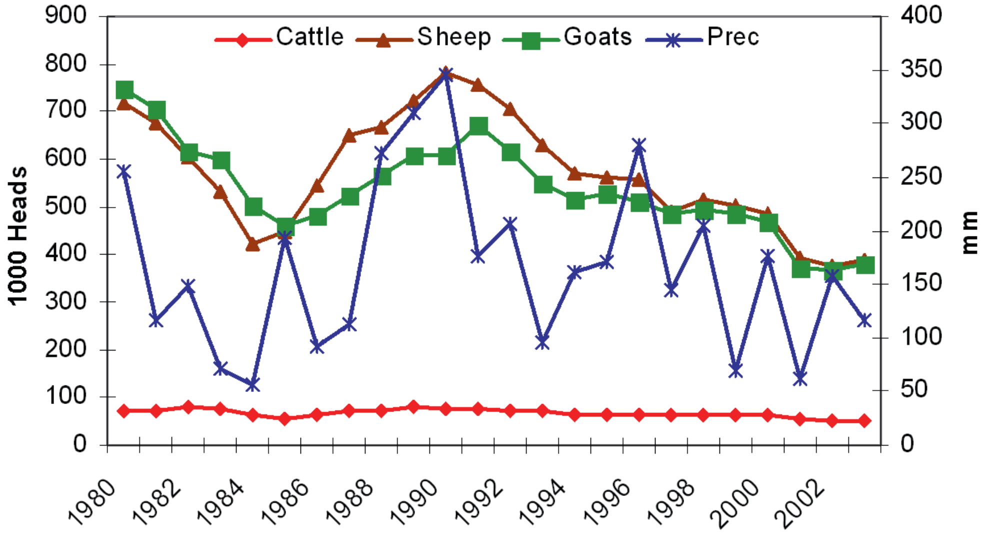

Fig 2: *Number of animals in the Drâa region from 1980 to 2003, Source: ORMVAO, 2003.*

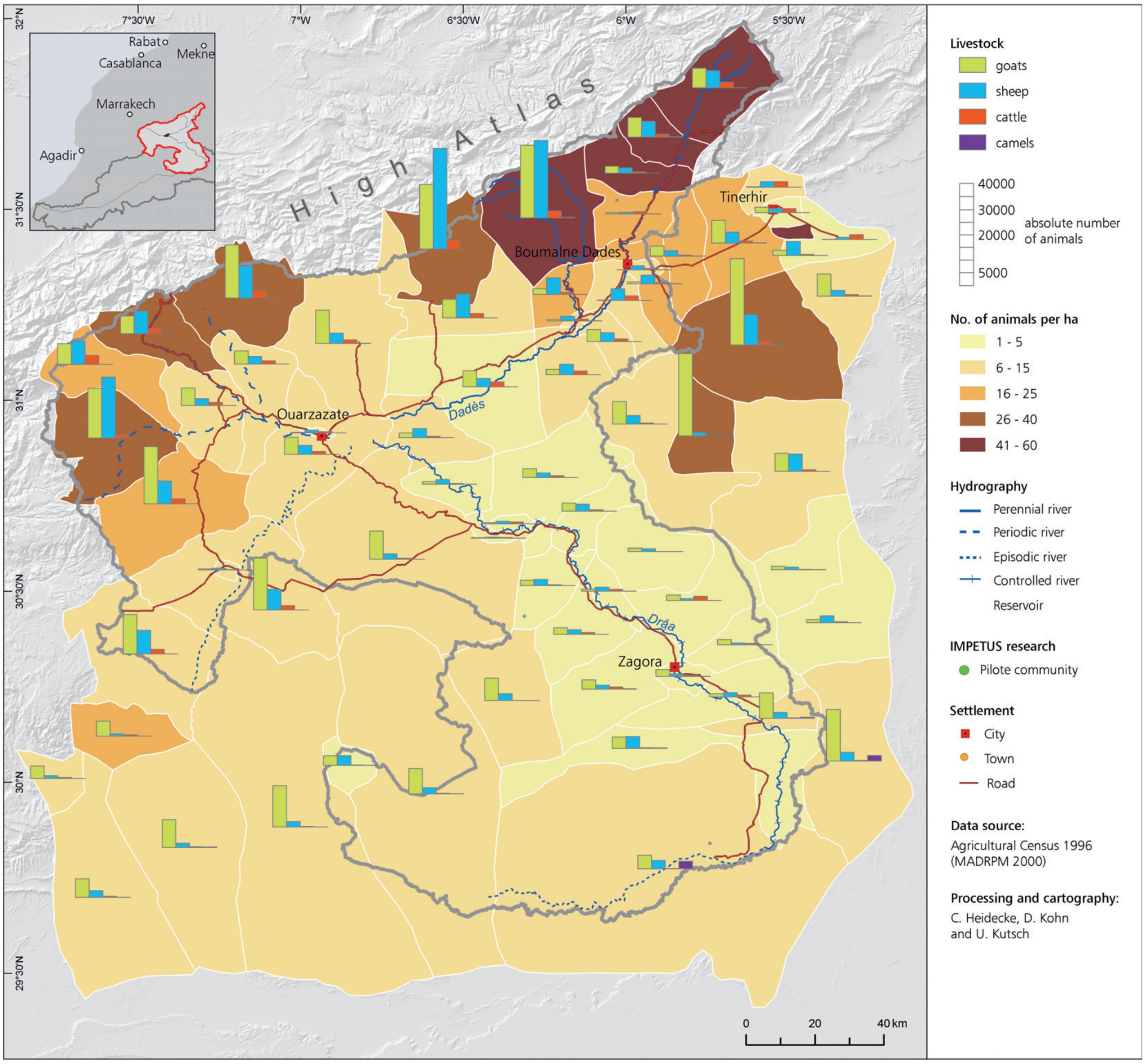

Fig. 3: *Livestock in the Drâa region on a communal level in 1996.*

28

Agricultural Land Use

Claudia Heidecke and Tanja Schmidt

Agriculture is a major activity for people in the Drâa region. Agricultural products are mainly used for auto consumption to feed large families but also for auxiliary income. Cereals and fodder for animals are the major crops. Date palms and henna used to be cultivated as cash crops, but during the last years these products have been increasingly used for own consumption as well.

Introduction

The last agricultural census in the Drâa region took place in 1996. Since then, agricultural production has changed significantly in the area. Due to droughts and changing prices, cultivation patterns have shifted; many people have migrated to larger cities and rented out land to neighbours. Therefore, data from the agricultural census is compared with more recent data from a farm survey by IMPETUS in the oases (↗ 5, 6, 19, 26, 27, 29, 30, 31, 32, 33).

Methodology

A farm survey was conducted in 2005 and 2006 to analyse aspects of agricultural production, irrigation and farm strategies in the Drâa region. Altogether, 280 farmers of the six Drâa oases Mezguita to Mhamid, and of the regions of Ouarzazate, Skoura, Kalaat Mgouna and Boumalne de Dades were interviewed with a standardized questionnaire.

The sample is not representative for the overall region, as farmers in the High Atlas and the rangelands are not included and the sample covers primarily larger agricultural exploitations (Fig. 1). Especially in the Middle Drâa Valley, an average farm size of 4.5 ha would exceed the total area cultivated. In 1996, 22,489 farmers cultivated 37,049 ha in the province of Zagora, leading to an average farm size of 1.6 ha/farmer (Agricultural census 1996). Thus the sample represents bigger farmers in the Drâa Valley than average.

Agricultural production

The major crops cultivated in the Drâa region are cereals and fodder for livestock (around 90 %) (↗ 27). The main cultivated cereal is wheat. Maize is grown in the summer months and requires a lot of water (Fig. 2).

In addition to annual crops, palm trees and fruit trees also serve as an income source. According to the survey data, an average farmer owns around 300 date palms in the Drâa region. Most dates are sold at local markets. In the Dades Valley, roses, olive trees and apple trees serve as income sources.

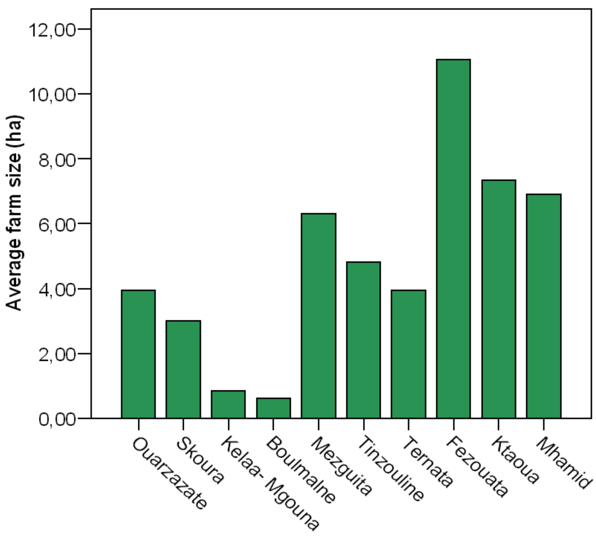

Fig. 1: Average farm size of different oases in the Drâa Valley in 2005.

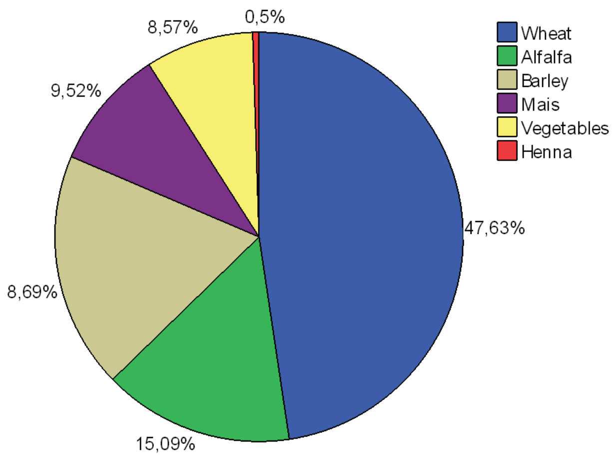

Fig. 2: Crops cultivated in the Drâa region (in %).

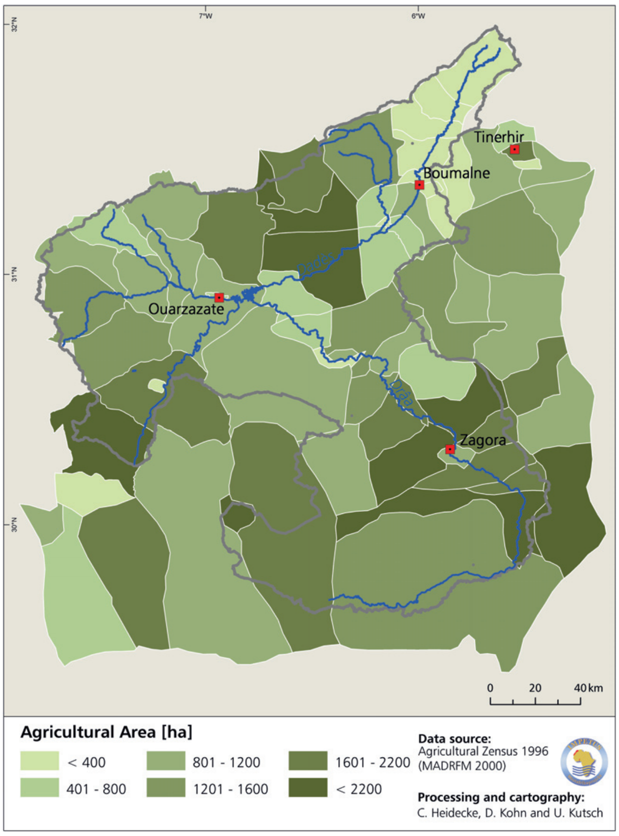

Fig. 3: Agricultural area (communal level in 1996).

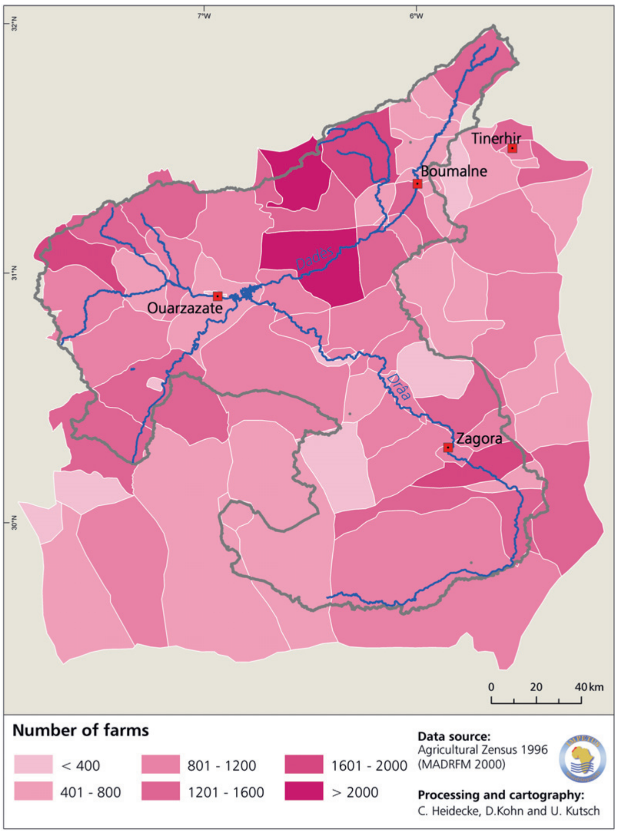

Fig. 4: Number of farms (communal level in 1996).

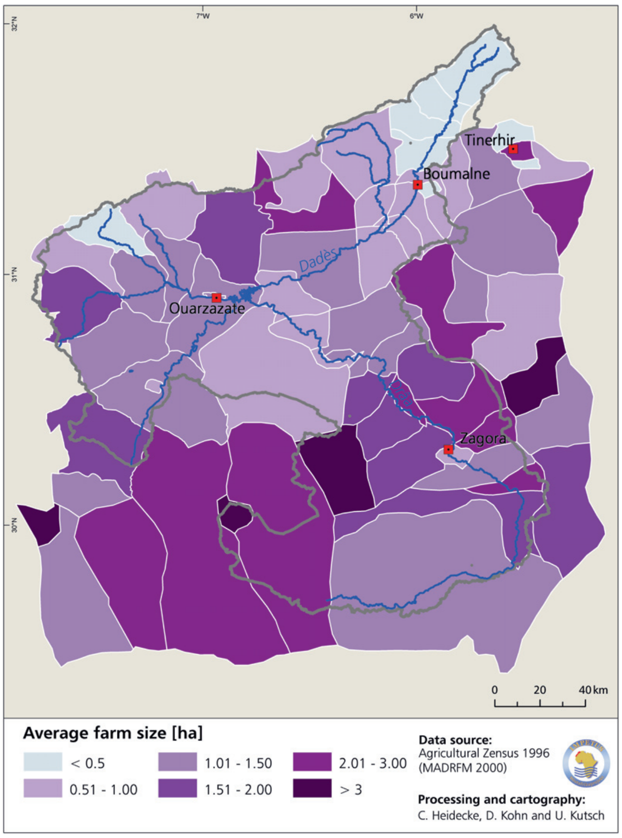

Fig. 5: Average farm size (communal level in 1996).

Figures 3 to 5 show the total agricultural surface, the number of farms and the average farm size at the communal level. The number of farms and total agricultural surface result from the Moroccan agricultural census, and allow for a calculation of average farm size. Agricultural land comprises arable land (land that was cultivated with annual crops at least once in the four years before the census was conducted) and land cultivated with permanent crops.

Data Source

Ministère de l'Agriculture, du Développement Rural et des Pêches Maritimes (ed.) (2000): Recensement Général de l'Agriculture: Résultats par Commune, Région: Souss-Massa et Drâa.

29

Agricultural Structure in Ouled Yaoub

Andreas Roth

Agriculture is still the most important income source in the central Drâa region. As data on agricultural products are mostly provided only at regional scales, we conducted a more detailed case study in the village Ouled Yaoub (Oasis of Tinzouline, central Drâa region). We evaluated the crop distribution and water regime of the fields to obtain most important parameters needed to assess land use and productivity at the local level.

Introduction

Agriculture in the Drâa region is mostly for subsistence and local consumption; marketable products play a minor role. One exception is the production of dates, which generate additional income. Most farmers cultivate similar crop mixes consisting of alfalfa, cereals (sweet corn, barley, maize), henna (in the south) vegetables (tomato, potatoes, onion, beetroot), fruit trees and date palms. Husbandry is widely practised in this region to provide additional income (↗27). We describe and analyze the agricultural structure of Ouled Yaoub as a typical example of the central Drâa region (↗15, 21, 26, 28, 30, 31, 32, 33).

Methodology

Table 1 illustrates the percentages and corresponding acreages of total crops cultivated in Ouled Yaoub in October 2005.

The overall cropping area of this oasis is 7.07 ha, thus more than half of area remains untilled due to fallow practise, water shortage and other reasons. Alfalfa, wheat and vegetables occupy similar areas, and in autumn these represent the most important crops, making up 72.8 % of all crops cultivated.

Various vegetables are cultivated throughout the year, according to preference. Hence, vegetables are particularly relevant, and their cultivation is facilitated by water from irrigation wells. Date palms strongly benefit from the irrigation system, and occupy a seemingly small area as boundaries between fields and serving, for example, as shade to field crops. The numbers for barley and sweet corn emphasise the importance of these crops. Henna, with only 3.9 %, takes fifth place, but is very culturally important. These figures illustrate the relatively small cultivated area compared to the potential. We hypothesise that is this is due to water shortage. The crop map is based on cartographic work (Fig. 1) for administrative borders of the agricultural area. Crop figures were obtained through map analyses.

The map data were made available by the agricultural authority ORMVAO.

***Tab. 1:** Crop mix at Ouled Yaoub, percentages and acreages (October 2005).*

fruit/crop	area [%]	area [ha]
alfalfa	24.8	0.64
barley	1.6	0.04
date palms	15.9	0.41
henna	3.9	0.10
untilled		4.59
sweetcorn	1.9	0.05
vegetables	23.6	0.61
wheat	24.4	0.63
sum	96.1	7.07

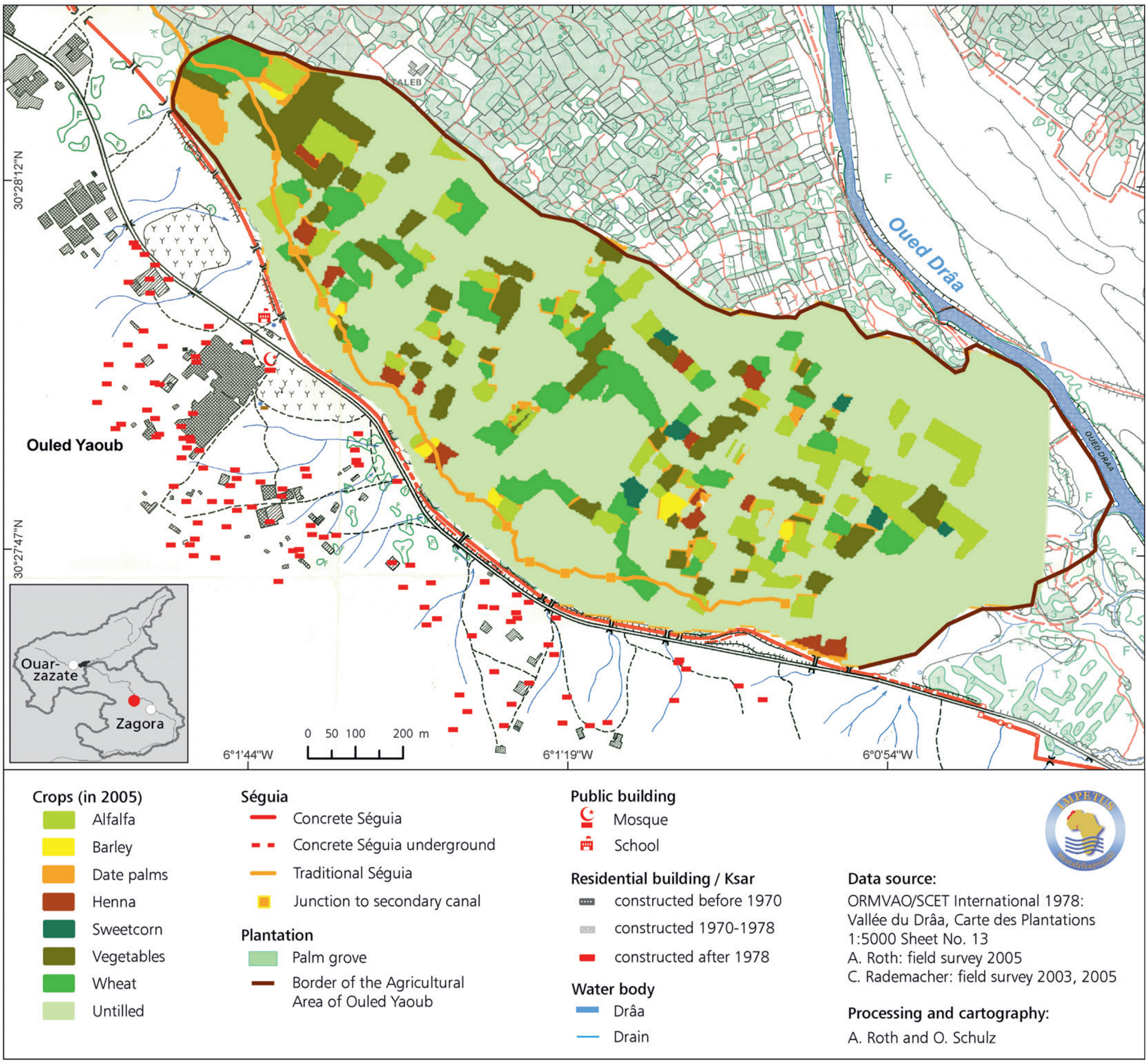

Fig. 1: *Tillage in Ouled Yaoub (Oasis of Tinzouline, Middle Drâa Valley) in 2005.*

30

Irrigation in the Drâa Region in 2005

Claudia Heidecke

After the construction of the Mansour Eddahbi reservoir in 1972, the number of motor pumps increased tremendously in the Middle Drâa Valley compared to the Upper Drâa region. The results of a farm survey in 2005 support this statement by showing that most farmers own more than one motor pump in the Middle Drâa Valley. The number of hours pumped per day is also significant.

Methodology

A farm survey was conducted in 2005 and 2006 to analyse aspects of agricultural production, irrigation and farm strategies in the Drâa region. Altogether, 280 farmers of the six Drâa oases Mezguita to Mhamid, as well as of Ouarzazate, Skoura, Kalaat Mgouna and Boumalne de Dades. were interviewed. The sample is not representative for the overall region, as farmers in the High Atlas and the rangelands were not included, and the sample represents primarily larger agricultural exploitations (↗ 28).

Irrigation water

Most farmers in the Drâa Valley depend on irrigation for crop cultivation (↗ 17, 18, 28, 29, 32, 33).

In the 70's, water for irrigation was mainly drawn from the Drâa River, but during the last decades, irrigation with surface water has been increasingly supplemented or substituted by irrigation with groundwater by farmers in the Middle Drâa Valley. Nowadays, farmers in the Drâa Valley use mainly groundwater for irrigation, whereas in the Dades region, surface water still seems to be the major water source (Fig. 1, ↗ 31).

Irrigation quantities

Many farmers in the Middle Drâa have complained about falling groundwater tables and hence higher extraction costs for pumping.

The variable costs for groundwater pumping have been analysed. Table 1 shows results for variable pumping costs per oasis, including the costs of gas, oil and maintenance, and provides total costs per cubic meter assuming that on average a motor pump delivers 17 m^3 per hour (measured by Klose, 2005). The costs vary by oases especially, due to different costs of maintenance of the motor pumps.

On average, a cubic meter of pumped groundwater costs a farmer 0.58 Moroccan Dirham in 2005. This exceeds the operation and maintenance costs charged for irrigation water in most other river basins in Morocco (Tsur et al., 2004).

The average number of wells and pumps per agricultural farm is displayed in Fig. 2. The great difference between the Drâa and the Dades Valleys becomes obvious. However, an average of one and a half motor pumps in the Drâa Valley is only realistic at the bigger agricultural exploitations.

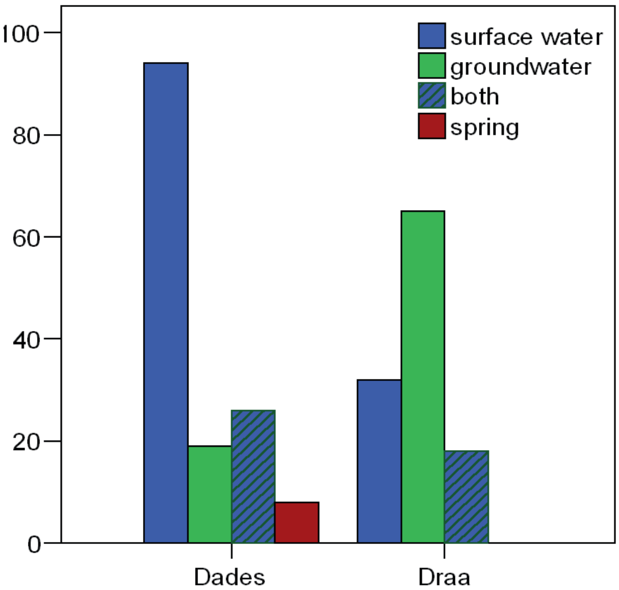

Fig. 1: Sources of irrigation water (numbers of farmers)

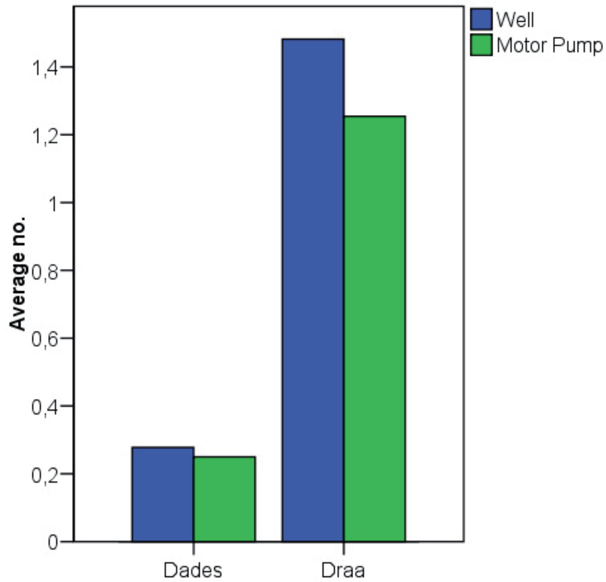

Fig. 2: Number of wells and pumps per farmer

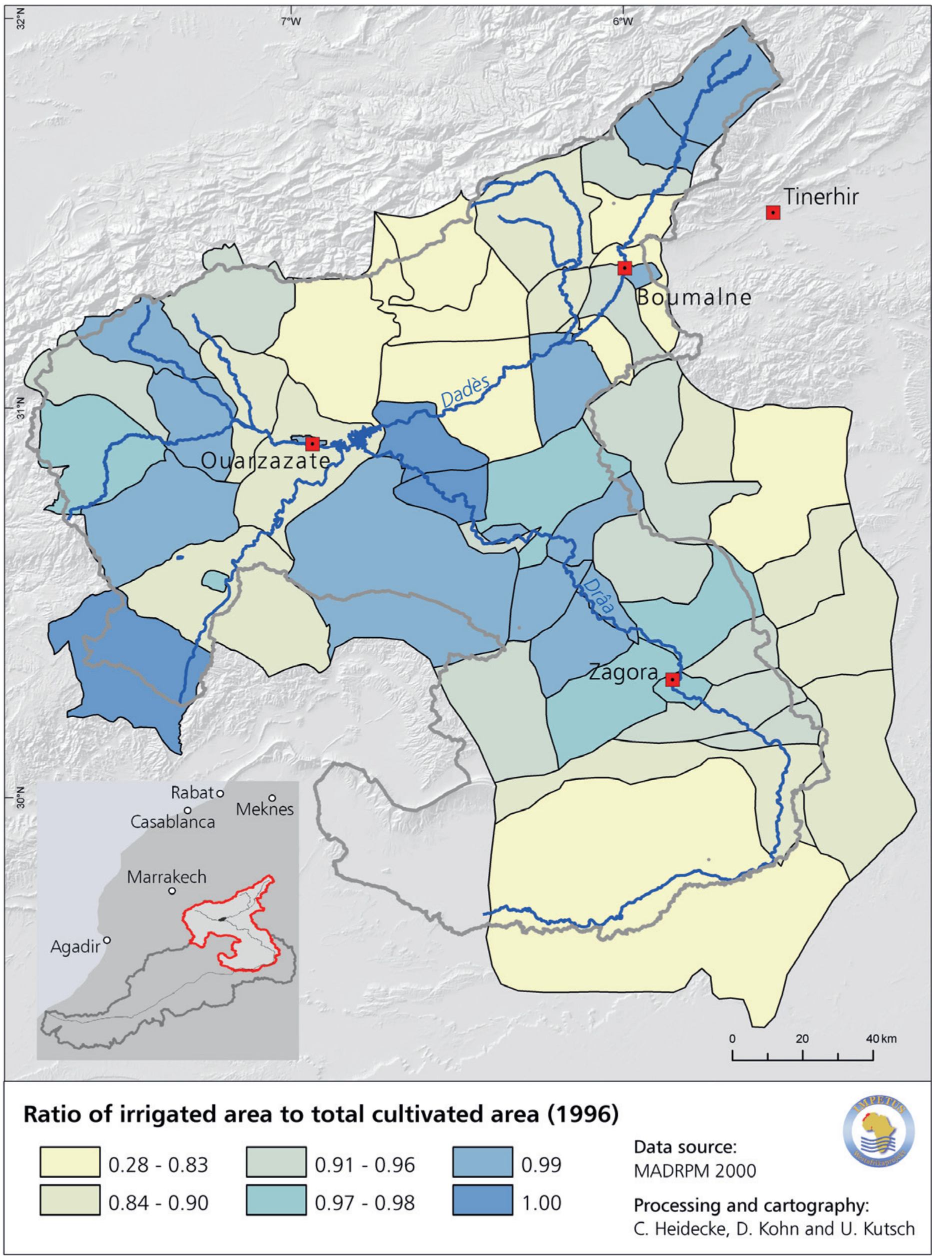

Fig. 3: Irrigated area in the Drâa region on communal level.

Irrigated area on communal level

Figure 3 shows the percentage of irrigated area to total area used for crop cultivation. The data illustrate the results of the last Moroccan agricultural census carried out in 1996–1997 (Ministère de l'Agriculture, du Développement Rural et des Pêches Maritimes 2000). The definition of irrigated area is as follows: a plot is marked as irrigated if it was irrigated artificially at least once during the agricultural year 1995–1996 (September 1995–August 1996). Note that precipitation in 1995/96 was higher than average.

***Tab. 1:** Pumping costs in the Middle Drâa Valley in 2005.*

	Cubic meters (m^3/day/pump)	Total cost (Dh/m^3)
Mezguita	127.84	0.63
Tinzouline	88.45	0.63
Ternata	76.50	0.62
Fezouata	127.50	0.49
Ktaoua	34.27	0.46
Mhamid	55.13	0.63
Average Costs	84.95	0.58

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Ministère de l'Agriculture, du Développement Rural et des Pêches Maritimes (ed.) (2000): Recensement Général de l'Agriculture: Résultats par Commune, Région: Souss-Massa-Draa, Rabat.

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Agricultural Strategies: Irrigation Management, Risk Diversion and Crop Rotation in Tichki

Holger Kirscht

This case study focuses on the management strategies practiced by farmers in the mountain community of Tichki, which is located in the Central High Atlas. Although the Atlas region has a surplus of precipitation, cultivation requires irrigation because of the unequal distribution of the precipitation in the area. As in other regions of the working area, differing water and land rights coexist. The strategies employed by local farmers for the purposes of guaranteeing necessary levels of production and minimizing risks of failure are well suited for Tichki's semi-arid, mountainous environment.

Introduction

This study examines how a local community copes with an environmental situation characterized by limited natural resources. The economic strategies of farmers were studied in relation to the ecological potential of the environment. Although water availability in the High Atlas is not as limited as it is in other regions of the Drâa catchment, it is clear that water is the most important limiting factor for agricultural production (↗ 6, 8, 17, 19, 20, 28, 29).

Tichki – the valley

Permanent settlement in Tichki village (2200 m a.s.l.) is a relatively recent phenomenon; up to the 1970's, some families did not have permanent houses. Tichki is a small village with about 290 inhabitants living in 28 households. The average household size is rather small (7.5 p/h). The families belong to one of four lineages or "grande familles", which are the "original" or first permanent settlers in the valley.

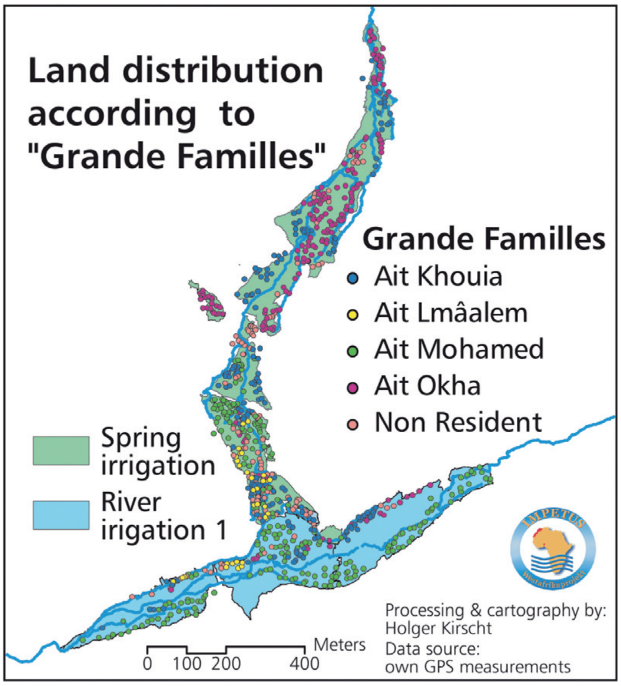

Fig. 1: Land distribution in spring and river irrigated areas.

Traditional irrigation

For irrigation in Tichki, people rely on two sources: the main river and springs which feed the river through a side valley. Water is "owned" and distributed according to two water right systems. The *mulk*-system which is practised in the river valley, and the *allam* or *afalys*-system, practised in the side valley. Under the *allam*-system, water rights are tied to the ownership of specific plots of land. Land can only be sold or inherited with the plot of land's concomitant water-rights. Irrigation depends on the location of a field and the demand of the crop. Fields are irrigated in sequence, regardless of who is the owner of the field. Sixteen irrigation sectors exist. One complete irrigation cycle takes approximately nine to twelve days. The *allam/afalys*-system is used if water resources are sufficient. Arrangements between upper- and downstream riparian owners are also necessary.

Under the *mulk*-system, water rights are independent of rights over land. Water and land can be given away, sold, or inherited independently. Families or individuals own parts of the irrigation canals and the right to use irrigation water during fixed periods of time (*nouba*). During this time-slot the farmer is entitled to irrigate his fields, regardless of the position of his field. Nine *noubas* exist in Tichki and each lasts one day. Water is divided among the four lineages and the downstream village of Tichki Tahtani. The Ait Khouia and others receive forty-eight hours of water, the Ait Mohammed, ninety-six hours, the Ait Lmâalem, twelve hours, the Ait Okha, twelve hours, and families in lower Tichki, forty-eight hours. The *nouba*-system is used to man age scarce and contested resources (↗ 30, 32, 33).

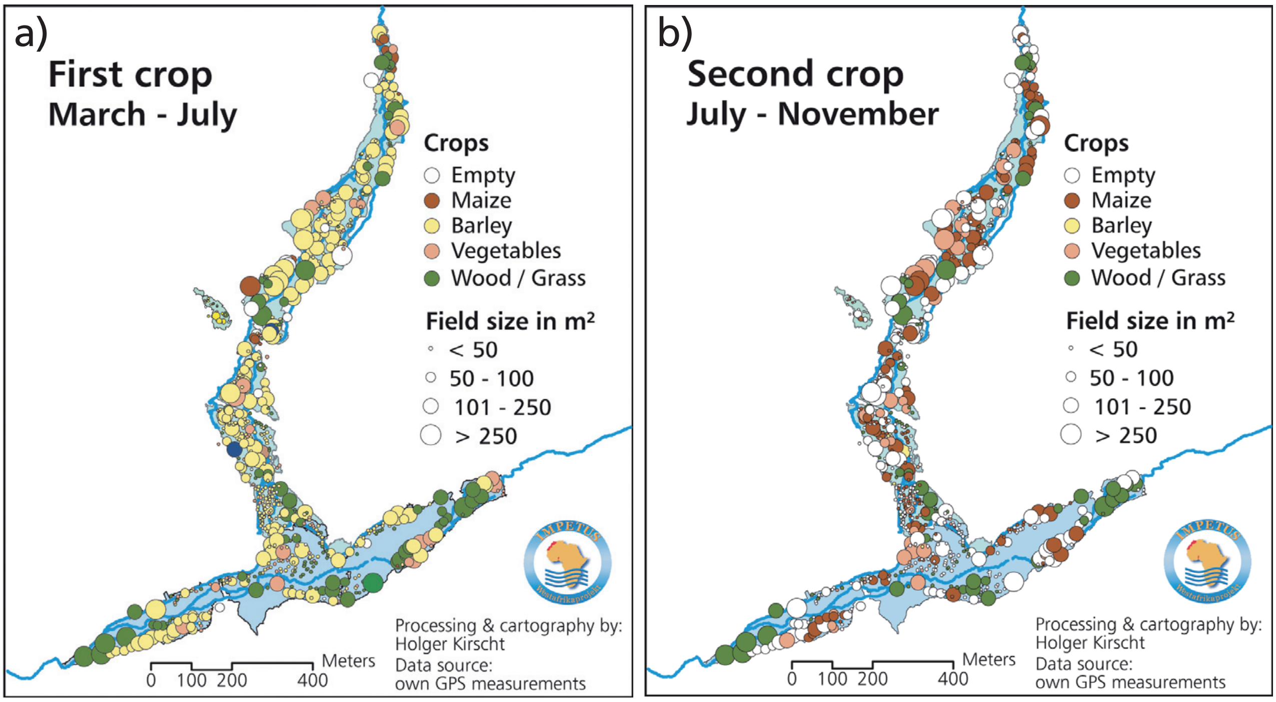

Fig. 2: *Distribution of (a) spring and (b) summer crops*

Strategy - diversified field ownership

Although both lineages and individual families tend to diversify their ownership of fields spatially, certain possession patterns exist due to the original processes of land acquisition (Fig.1).

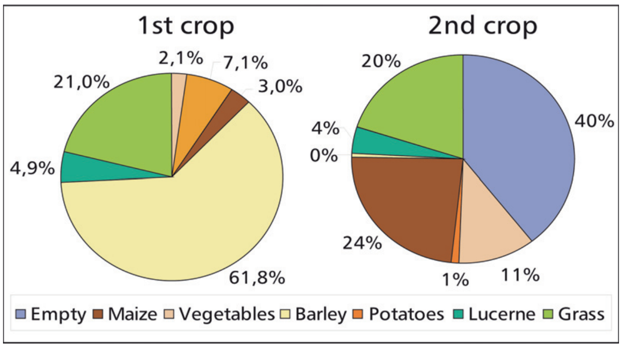

Fig. 3: *Percentage of main crops during the first and second cultivation cycle*

Lineages prefer to own land both on the river valley and on the side valley. Such a diversification of land ownership allows the lineages to protect themselves from potential disaster in either valley, whether it be crop failure due to low water levels or if it is a natural disaster such as a landslide.

Strategy - crop selection and rotation

Two crops per year are planted (Figs. 2, 3). Barley and potatoes are the dominant first crops, and are planted in the spring. Maize and vegetables, the dominant second crops are planted in summer and in autumn. Each of the crops is farmed primarily for domestic consumption. Nuts and, more recently, apples constitute the most important cash crops.

Cultivation is continuous; only a few fields lay fallow during autumn. Three crop-rotation cycles are practised (Tab.1). Fruit and nut-trees, as well as the grasslands and the poplars that are grown close to the watercourses, are permanent cultures. Crop rotation and yield depends on the soil quality and the location of the fields in the irrigation system.

Tab. 1: *Crop rotation cycles*

1st crop	2nd crop	cycle
Barley	Fallow	1 year
Barley	Maize	1 year
Barley	Maize	4 years
Barley	Potato	
Barley	Maize	
Barley	Carrot / turnip	

Conclusion

People in Tichki use environmentally adapted land and water management systems. Nevertheless, Tichki's growing population and environmental constraints form a major challenge for its land and water management systems. Extending the agricultural area is not an option, for there is neither enough available water nor useful land. Labour-migration is often considered as the only alternative option to local farming (↗ 26).

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Traditional and Modern Irrigation in Ouled Yaoub

Christina Rademacher

In arid regions, irrigation systems are of crucial importance for oasis agriculture. In the Drâa Valley, diverse irrigation systems exist with differing property rights. Sometimes water rights are connected to land rights (meaning that land cannot be bought or sold without water rights) and in other regulations, water rights can be bought and sold independently. The positive and negative aspects of both traditional and modern irrigation systems will be clarified though a case study example.

Introduction

This study explains the functioning of the free-of-charge, traditional irrigation in Ouled Yaoub and the reasons for today's dominant use of modern, cost-intensive motor-pump irrigation. The current situations of water-supply and the water demand for both agricultural and domestic purposes are important as well.

Methods

During long-term fieldwork (2002–2006), all wells for agriculture and domestic use were measured by GPS and mapped in a GIS which is based upon the "Carte des plantations" (ORMVAO, 1975). Local statements about the quality and quantity of water, as well as information about coping strategies of farmers, were collected.

Traditional irrigation

Traditional irrigation has been carried out according to one general scheme: water is diverted from the Drâa River via irrigation channels (Seguia) to the fields (Fig. 2). Every farmer owns certain rights to land and water. After the construction of the dam, Mansour Eddahbi, in 1972, water outlets (lâchers) have been restricted to three or four times in dry years (↗ 17, 29, 30).

In December 2005, water was available for six days in Ouled Yaoub. According to a complex distribution system, every farmer was allocated a fixed period of time for irrigation, depending on the amount of personal water rights and total water availability. The time and day for irrigation were fixed by random selections. It is important to note that during each lâcher, the time equivalent of the irrigation unit (nouba) is fixed anew. In March 2004, one nouba lasted six hours, while in December 2005 it lasted only two hours.

Independent of the number and size of their fields, 19 % of the water owners were allocated less than two hours of irrigation and another 19 % of water owners were allocated less than four hours (Fig. 1). Even the most privileged farmers irrigated only for nineteen hours. Compare this amount of irrigation to the local traditions of water irrigation, where one 3,000 m² sized field of wheat is watered seven times for eighteen hours until it is harvested.

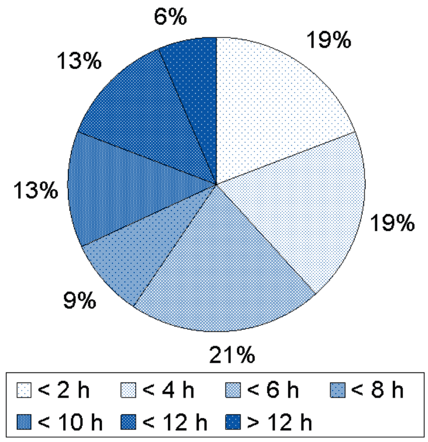

Fig. 1: Distribution of irrigation water according to water rights owners. Lâcher December 2005, 6-days-cycle.

To conclude, the modified traditional irrigation system does not satisfy the water needs of the farmers.

Motor-pump irrigation

There was a dramatic increase in the number of wells in the Drâa valley after the construction of the dam (Faouzi, 1986). The map shows the distribution of wells for agricultural and domestic use in Ouled Yaoub. Most of the sixty-three agricultural wells have motor-pumps. The use of subterranean aquifers has led to a decline both in the groundwater level and in the quality of the water.

Domestic irrigation

Additionally, women of the 102 permanent households fetch water from 61 domestic wells. Results of a water consumption survey in 2005 revealed that 21–40 litres (depending on family size) were used per person per day (↗ 15, 21, 33).

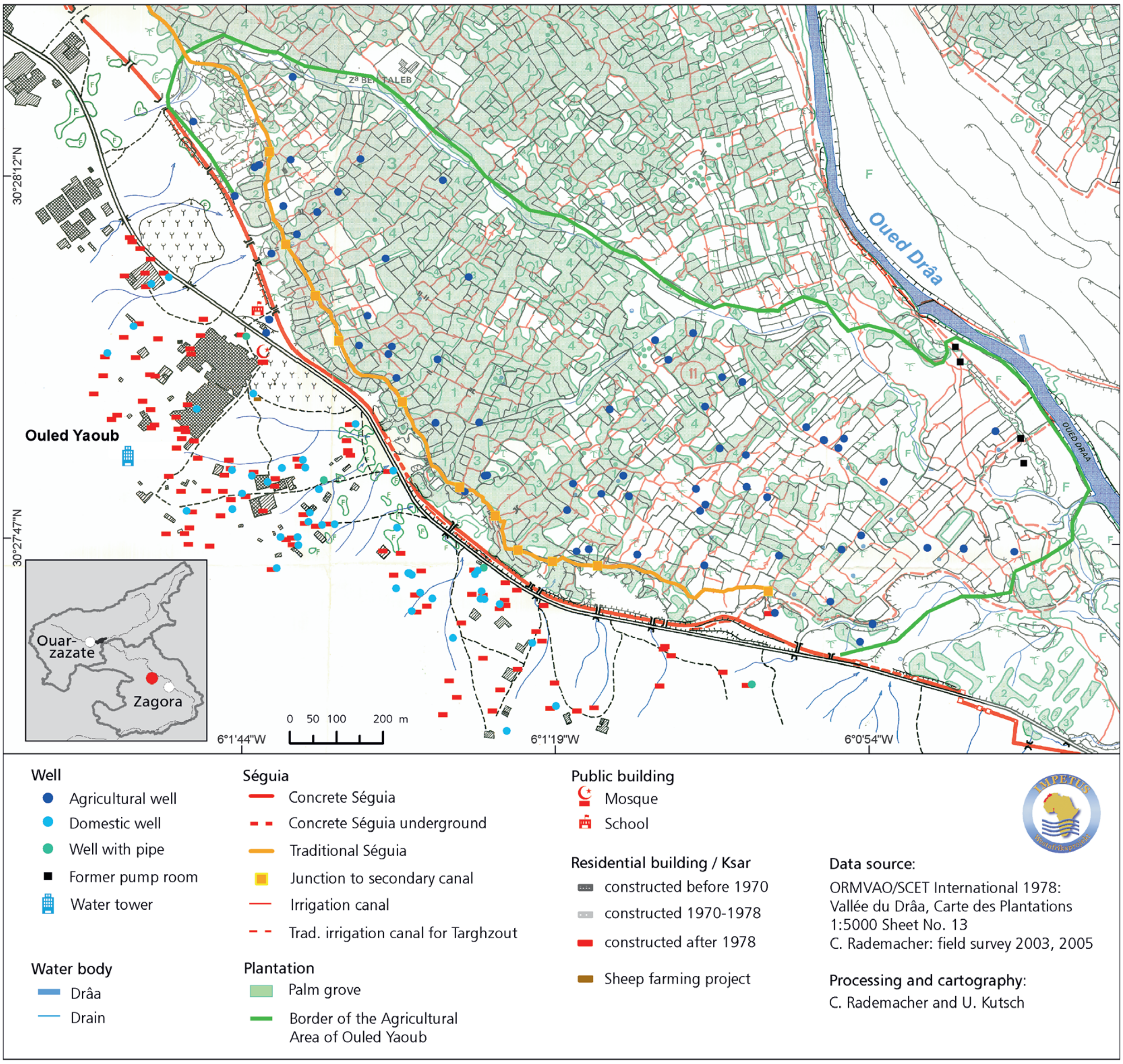

Fig. 2: *Water supply for households and agriculture in Ouled Yaoub, Oasis of Tinzouline, Middle Drâa Valley.*

Conclusion

Neither the old irrigation system nor modern motorpumps satisfy the farmers' urgent water needs. Modern irrigation is cost-intensive (i.e. construction, fuel for pumps) as each household has to have more than one income resource if they intend to employ modern irrigation technology. Migration became the most common strategy of survival in the oasis. Remittances enabled villager's o finance local agriculture and modern irrigation tools (↗ 26).

Data sources

Fieldwork and interviews: C. Rademacher

ORMVAO (1975): Vallée du Drâa, Carte des plantations 13, 1:5000.

Faouzi, A. (1986): Distribution de l'eau dans le Drâa Moyen, ORMVAO.

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Investments in Land and Water Rights in Ouled Yaoub

Christina Rademacher

For a society traditionally based on agriculture, possession of land and water is an important indicator of status, determining whether an individual is honourable or whether his/her origin is ambiguous according to the terms of local social ascriptions. Investing in land and water rights is therefore a means of achieving both upward mobility and prestige.

Introduction

Three different ethnic groups reside in Ouled Yaoub: Arabic groups, the Draoua, and the Haratin (these terms are the local classification). These varying ethnic groups are socio-politically organized into four lineages (Arabic term: *firqat*). They are divided in two Arab groups, a mixed group that contains both Arabs and Haratins, and a fourth group that consists of Draouas. Of the 102 households, 65 % are of Arab origin, 30 % are of Draoua origin and only 5 % are of Haratin origin.

In hierarchically structured societies dominant ethnic groups possess the majority of land and water like the Arabs in Ouled Yaoub in the past. The question arises whether this situation has changed today with heavy out migration of all ethnic groups. Furthermore, if there have been changes, what are the reasons for these changes? This paper addresses questions about how the social order has changed, with particular reference to how land and water distribution functioned as an indicator of social status.

Methods

In 2003, a survey was conducted for the purposes of assessing the land possession of each household. It was impossible, however, to learn the exact size of each field both because farmers were unable to provide such information and because it was impossible to measure the size of each field. Interviews were conducted with local land and water rights experts in order to learn both the historical as well as actual situation as well as what changes that have occurred over time. The basis of this study's detailed comparison was land registration data (ORMVAO) from 1978. This land registration data contains information about each household's total land possession and about the field sizes.

Historical background

The Drâa Valley, having experienced several waves of immigration throughout its history, is a melting pot of different ethnic groups. With each occurrence, these waves of immigration have brought changes to the socio-political setting. In the first half of the twentieth century, Arab groups dominated many parts of the Valley.

In Ouled Yaoub, Arabs were large land owners that employed Draoua and Haratin to cultivate their fields. The Draoua and Haratin worked in patron-client-relationships for one-fifth of the harvest (*Arabic*: khammes).

After the country's independence in 1956, migration to the new economic centres of Morocco started and expanded quickly. From the 1970's onward, people of disadvantaged social groups like the Draoua, but also Arabs, were migrating. Migrants started sending remittances to their families and villagers were able to invest in housing and agriculture (↗ 3, 26).

Land and water rights

Investments in agriculture included the purchase of land, water rights, and motor-pumps. The distribution of land and water today, after nearly four decades of migration, is displayed in Fig. 1.

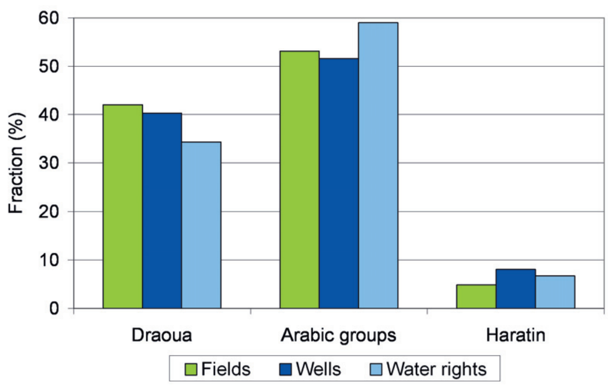

Fig. 1: Distribution of fields, wells and water rights for each ethnic group in 2003.

The Draoua, who form 30 % of the households, possess 42 % of the land. Arabs, meanwhile, constituting 65 % of the households own 53 % of the land. As the traditional source of irrigation, surface water from the Oued Drâa, is less important to farmers today, villagers prefer to invest in the installation of wells with motor pumps. (↗ 30, 32)

It is important to understand how the current situation compares to the state of affairs at the end of the 1970's, when the mass labour migration was just beginning.

The number of fields and their sizes in the "Etat parcellaire" from 1978 have nearly the same numerical value, which allows for a comparison of the distribution of fields between these two points of time.

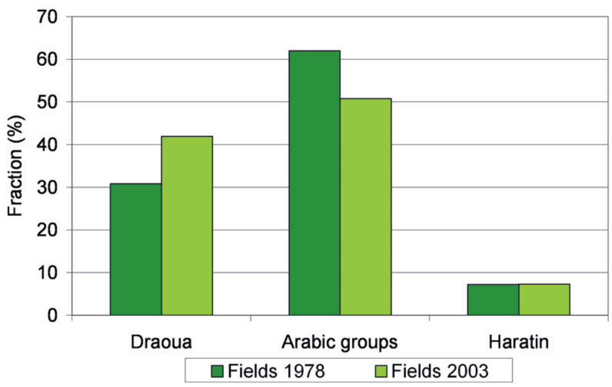

***Fig. 2:** Comparison of distribution of fields 1978 and 2003.*

Figure 2 illustrates that the disadvantaged Draoua became able, financially, to invest in land as well as traditional and modern irrigation techniques. Compared to the Arab groups, the Draoua invested more in agriculture than did their former landlords. Since each group participated in migration, it is curious that the groups differ in their level of agricultural investment. The composition of households reveals that the Arab groups have had a tendency to form families of middle or small size. Of the three Arab groups, only 7–23 % have more than 10 persons per household, while 40 % of the Draoua households are extended families. Household divisions imply the division of inheritance portions, whereas in extended families, the property is held in common. The Draoua, obviously, stick to more traditional, extended family norms.

Viewing land possession according lineage, the Draoua possess more land than any single Arab lineage. In local political terms, this is important because the internal conflicts that plague the Arab groups give the Draoua an even more important standing in local decision-making processes.

Today, Arabs invest more in the higher education of their children than in agriculture, while the Draoua continue to invest in the land.

Investments in agriculture

A ranking of income resources (survey 2006, 20 households) of each surveyed household indicates that migration is given first or second priority, before agriculture, commercial activities, livestock trade, or salary. The income distribution is as follows: 69 % of the total income of all surveyed households consists of transferred money from migrants (remittances), 18 % from agriculture and 13 % from other sources. Households with international migration invested more in agriculture than did households with national migration. Households with international migration, therefore, had a higher agricultural income. A cost-benefit-calculation revealed that in most cases, agriculture has become so cost-intensive (i.e. motor pumps, fuel, fertilizer) that it is not profitable any more. People said it was cheaper for them to buy vegetables from the local market (*souq*) than to cultivate them. Thus, 30 % of the households stopped working in agriculture, while 25 % of the households produced only enough for self-consumption.

Every household that made a net profit had additional income from sources other than agriculture, such as taxi-driving or renting agricultural equipment, to name only a few (↗ 15, 17, 21, 24, 29, 31).

Data sources

Field survey and interviews: C. Rademacher
ORMVAO (1978): Land register data (Données du Cadastre).

Abbreviations

A1B	a climate change scenario based on SRES, defined by the IPCC
ATL	Atlantic region
B1	a climate change scenario based on SRES, defined by the IPCC
CRU	Climate Research Unit (at the University of East Anglia)
DEM	Digital Elevation Model
DRH	Direction Régionale Hydraulique
EC	Electric Conductivity
ECHAM	European Centre Hambourg Model
ESRI	Environmental Systems Research Institute
ETM	Enhanced Thematic Mapper
GDP	Gross Domestic Product
GHCN	Global Historical Climatology Network
GIS	Geographic Information System
GLOWA	Globaler Wasserkreislauf (German Global Change and the Hydrological Cycle Initiative)
GPS	Global Positioning System
GSFC	Goddard Space Flight Center
ha	hectare
HCEFLCD	Haut Commissariat aux Eaux et Forêts et à la Lutte Contre la Désertification
IHP	International Hydrological Program
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)
IPCC	Intergovernmental Panel on Climate Change
IS	Information System
MED	Mediterranean region
MODIS	Moderate Resolution Imaging Spectroradiometer
MT	Monitoring Tool
NASA	National Aeronautics and Space Administration
NDSI	Normalized Difference Snow Index
ORMVAO	Office Régional de Mise en Valeur Agricole de Ouarzazate
OSS	Sahara and Sahel Observatory
PESERA	Pan European Soil Erosion Risk Assessment
REMO	Regional Model
RMSE	Root Mean Square Error
ROSELT	Réseau d'Observatoires de Surveillance Ecologique à Long Terme
RSC	Residual Sodium Carbonate
SAR	Sodium Absorption Ratio
SDSS	Spatial Decision Support System
SE	Service Eau
SOA	South of the Atlas Mountains (Atlas region)
SRES	Special Report on Emissions Scenarios
SRM	Snowmelt Runoff Model
SRTM	Space Shuttle Radar Topography Mission
SYNOP	Surface Synoptic Observations
UEB	Utah Energy Balance Model
UNESCO	United Nations Educational, Scientific and Cultural Organization
USGS	United States Geological Survey
VASCLIMO	Variability Analysis of Surface Climate Observations
WGS84	World Geodetic System 1984
WRB	World Reference Base for soil resources