2.6 Decadal Precipitation Variances and Reservoir Inflow in the Semi-Arid Upper Drâa Basin (South-Eastern Morocco)

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Abstract

Water resources in the Upper Drâa basin south of the High Atlas Mountains are of high importance for the persistence of human settlement in this region. To enlighten the hydro-climatologic situation, precipitation data from regional stations was analysed with respect to changes in annual precipitation sums and intensities. Then the inflow into the reservoir, its annual variability and its connection to precipitation events of different intensities was investigated. It was found that precipitation has a high variability that covers possible trends during the last decades. The study is concluded with an appraisal of the current and future hydrological regime of the Upper Drâa basin in the regard of water availability. Climate change is predicted to decrease annual precipitation sums but to increase precipitation intensities which leads to a higher number of floods. Since it was shown that floods provide most of the water volume for the reservoir Mansour Eddahbi, more research of the regional interdependencies is needed.

2.6.1 Introduction

Water resources in the Oued[1] Drâa basin (Upper Drâa 15000 km^2, Middle Drâa 14000 km^2), south of the High Atlas Mountains are of high importance for the persistence of human settlements in this region. For more than 780000 people (census 2004) concentrated more or less in the proximity of valleys within the provinces of Ouarzazate and Zagora the Oued Drâa and its upper tributaries deliver the base supply of water. There exists a general difference between upstream and downstream riparians of the reservoir Mansour Eddahbi near the city of Ouarzazate. While the Upper Drâa basin experiences an undisturbed hydrological regime of the semi-arid subtropics, the river Drâa downstream of the reservoir is controlled by

1. Oued is the traditional and current expression in north-western Africa for rivers with episodic to perennial runoff.

lâchers[2] which are managed depending on the refill level of the reservoir (current capacity: 460 Million m^3). During the last years there can be observed a decline in agriculture in the Middle Drâa Valley that was formerly well-known for its date production.

This study enlightens the hydro-climatological situation of the Upper Drâa basin represented by decadal variability of precipitation and inflow to the reservoir. In a first step, the precipitation at different climate stations with record lengths of more than 60 years is analysed with respect to changes in annual sums. In a second step, precipitation intensities, for the same stations and additional stations with shorter record lengths, are checked for trends within the last decades. The last step includes an investigation of inflow into the reservoir, its annual variability and its connection to precipitation events of different intensities. Outcomes are discussed with regard to the current and future regional water availability.

This study is a contribution to environmental monitoring and research undertaken by the Moroccan administration going back to the 1930s and the German IMPETUS[3] project that started in 2000.

2.6.2 Study area

The watershed of the Oued Drâa is situated on the southern slope and in the foreland of the High Atlas Mountains in south-eastern Morocco (Fig. 2.6.1). It is divided into three parts, the Upper, Middle and Lower Drâa Valley. Runoff rarely reaches the Lower Drâa Valley that takes course in south-west direction towards the Atlantic Ocean while draining the southern Anti-Atlas. So, from the hydrological point of view, investigations started in the High Atlas Mountains and ended at the formerly filled and nowadays normally dry end lake of Lac Iriki, which is situated at the Algerian border, and constituting the transition zone to the northern Sahara (Hamada du Drâa). This region corresponds to the research area of the IMPETUS project which is restricted to the Upper and Middle Drâa Valley. Lately, the Upper Drâa basin is in the scope of this article's investigation.

The Upper Drâa basin (15000 km^2) ranges from the High Atlas Mountains (up to 4071 m) in the north to the elevated plain of Ouarzazate (1100 m - 1400 m) and the bordering low mountain range of the Anti-Atlas and Jebel Saghro (up to 2500 m) in the south.

Due to the geological setting three domains can be distinguished corresponding to the main topographical zones. The domain of the High Atlas Mountains is dominated by outcropping Liassic limestones and Triassic sandy siltstones intercalated by basaltic intrusions. The Mesozoic rocks were folded and thrusted during the

2. Lâcher is a local expression for a period of water release from the reservoir for irrigation purposes.
3. The IMPETUS project is part of the GLOWA initiative and pursuits an integrated approach to the efficient management of scarce water resources in West Africa; www.impetus.uni-koeln.de; www.glowa.org

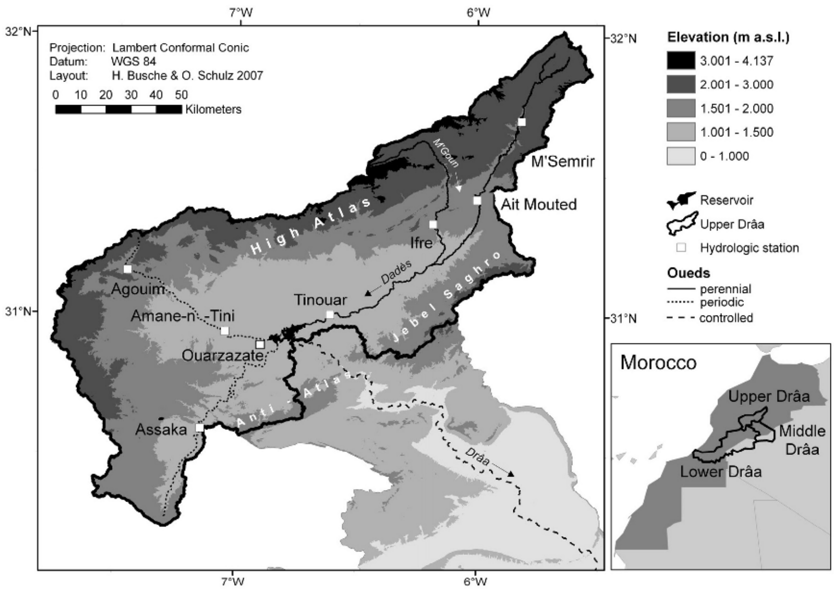

Fig. 2.6.1. Map of the study area with location of measurement stations.

Mesozoic and Neogenic orogenesis of the High Atlas. The Triassic rocks represent fractured media with largely low permeability. The partly karstic Liassic limestone can have medium to high permeability and plays the major role for direct groundwater recharge processes in the High Atlas Mountains (Cappy 2006, Cappy and Reichert 2005). Neogenic continental deposits of silt, sand and conglomerate prevail in the adjacent Basin of Ouarzazate. The Basin of Ouarzazate displays a complex multilayered aquifer system of both porous and fractured media of medium to high permeability. The northern slope of Jebel Saghro (Central Anti Atlas) is mainly built up by Precambrian rocks such as granites and rhyolites (Piqué 2001). Due to tectonic stress during the Eburnean, Pan-African and Hercynian orogenesis these rocks are fissured and have generally low permeability. Therefore river stream infiltration is the most important process of groundwater recharge within the Upper Drâa catchment (Cappy 2006, Cappy and Reichert 2005).

The climate of the Upper Drâa basin is semi-arid with remarkable differences in temperature and precipitation between the more humid High Atlas Mountains and the dry basin of Ouarzazate (Joly 1949, Hasler 1980, Schulz 2006). Situated in the subtropical zone on the leeward side of the principle climatic and weather barrier of the main mountain chain, precipitation is generated by three weather systems (Knippertz 2003, Knippertz et al. 2003a, 2003b, Speth and Diekkrüger 2006):

1. low pressure activity in mid-latitudes with storm-tracks reaching from the northwest over the High Atlas Mountain ridges during the winter months;

2. transport of moisture from the Atlantic Ocean, generated by troughs or cut-off lows located west of the Moroccan coast;
3. tropical-extratropical interaction from areas south of the Sahara with water vapour transport in higher elevations (>3 km) mainly in spring and autumn.

Annual precipitation sums in the High Atlas reach 800 mm (Joly 1949, Wiche 1953, DAF 1957) consisting of rain and snow which has a percentage of more than 50% in altitudes above 3000 m (Schulz 2006). The basin of Ouarzazate is usually dry with some rare but efficient precipitation events. Total precipitation adds up to 100-150 mm (stations Tinouar, Assaka Tafounante and Amane-n-Tini, Fig. 2.6.3).

The Upper Drâa basin experiences a semi-arid hydrological regime. Discharge is perennial only in the eastern high mountain part (Oueds M'Goun and Dadès). Downstream of the confluence of M'Goun and Dadès in the basin of Ouarzazate the Dadès flows to the reservoir Mansour Eddahbi. All other oueds are episodic and the discharge is generated only after efficient precipitation events or during snow melt (Riser 1973, Cappy 2006). The Mansour Eddahbi reservoir was opened in 1973. Through 2003 its initial capacity of 560 Mio. m^3 has decreased by 100 Mio. m^3 due to sedimentation (ABH Souss/Massa/Drâa 2003). The dam's functions are to supply the six date palm oases in the Middle Drâa Valley with controlled water portions of annually 250 Million m^3 for irrigation purposes (Pletsch 1971, Riser 1973, DRPE 1994) and to produce hydro-electrical energy.

Downstream of the dam, the Oued Drâa has cut a transverse valley through the Anti-Atlas and delivers water for irrigation of the date palm oases further south in form of lâchers. For most of the year the river bed is dry. The hydrological and hydrogeological setting and development of the Middle Drâa Valley is examined by Klose et al. (2007).

During the last decades a decline of agriculture can be observed in the Middle Drâa Valley that was formerly well-known for its date production (Fihri 2007). Today even the regional market is dominated by imported dates from Tunisia. During years of severe drought all stream water from upstream is stored in the reservoir. Only between one and three lâchers are executed in dry years to stop the decline of groundwater levels in the Middle Drâa Valley (ORMVAO 2003). Irrigation with surface water does not take place in dry years, so irrigation is only possible with groundwater which is increasingly extracted by motor pumps. The local population associates the observed decreased regional water availability with the absence of stream flow in the river bed after the construction of the reservoir (Rademacher in prep.; inhabitants of the Middle Drâa Valley, personal communication 2001-2006).

Table 2.6.1. Precipitation (P) at measuring stations, inflow (I) respectively runoff (R) into the reservoir Mansour Eddahbi (data provided by the DRPE Rabat and the Service Eau Ouarzazate).

Station	Coordinates	Elevation	Measured Variable	Time Series used
Agouim	31.01°N, 7.10°W	1647 m	P	1969-2003
Ait Mouted	31.43°N, 6.00°W	1545 m	P	1940-2003
Amane-n-Tini	30.94°N, 7.04°W	1170 m	P	1982-2003
Assaka-Tafounante	30.59°N, 7.14°W	1380 m	P	1975-2003
Ifre	31.34°N, 6.18°W	1500 m	P	1940-2003
Ouarzazate*	30.93°N, 6.90°W	1140 m	P	1940-2003
Tinouar	31.01°N, 6.61°W	1136 m	P	1974-2003
M'Semrir	31.71°N, 5.81°W	1942 m	P	1940-2003
Mansour Eddahbi reservoir	30.90°N, 6.75°W	1100 m	P R: Zaouïa-n-Ourbaz I: water balance	1973-2003 1940-1972 1973-2003

* The meteorological station Ouarzazate is operated by the National Moroccan Weather Service (Direction de la Météorologie Nationale) and accredited by the World Meteorological Organization.

2.6.1 Data and methods

In this study, the characteristics of precipitation and discharge in the upstream area of the reservoir Mansour Eddahbi (Upper Drâa basin) during the last decades are analysed. The database consists of regional measured records of precipitation and reservoir inflow provided by the regional water service (Service Eau de Ouarzazate, M. Sabbar) and by the National Water Secretariat at the Moroccan Ministry for the Management of Water and Environment (Secrétariat d'État aprés du Ministère de lAménagement du Territoire de l'Eau et de l'Environnement chargé de l'Eau, Rabat). Information about the stations is listed in Table 2.6.1, and their sites are mapped in Fig. 2.6.1. Precipitation recording at the Moroccan hydrologic stations used in this study goes back to 1930 (Ouarzazate), but other stations started later (the youngest station is Amane-n-Tini, which started in 1982). To cover the longest period possible and to be comparable with reservoir data, for the analysis of the long-term variability, only those records with more than 60 years of data were selected.

The hydrologic stations of the regional water service are of the manually operated type. They consist of discharge gauges and climate stations. A technician reads four times a day the current sums of precipitation, current air temperatures, psychrometric differences for the calculation of air humidity, just as wind direction and wind velocity. The climate stations are situated on open ground in the vicinity of the discharge gauges where water level in the river bed is measured with fixed staff gauges and with mechanical hydrographs. Discharge is calculated using frequently revised stage-discharge relationships. Before the reservoir Mansour Eddahbi was constructed, the runoff at the former discharge gauge of Zaouïa-n-Ourbaz was considered as theoretical inflow to the reservoir. This gauge was situated at the entrance of the Drâa gorge where the dam is located today. Since 1973 the daily inflow is calculated from water level changes, taking into account losses from evaporation, seepage and extractions for the water supply of Ouarzazate (DRPE 1988). Daily inflow data of the reservoir for 1998 to 2003 were analyzed including wet and dry years.

The methods used were normalizing annual sums of precipitation and inflow as well as classifying and cumulating daily precipitation data to provide a base for data interpretation. For every hydrological year the annual precipitation sum of the stations Ouarzazate, Ifre, Ait Mouted and M'Semrir was averaged to get one value for the area under investigation. This average value was normalized against the overall average of the record length (1940-2003).

Daily precipitation data of six stations distributed in the Upper Drâa basin was classified into six classes of intensity (0,1-5 mm, 5-10 mm, 10-25 mm, 25-50 mm, 50-75 mm, >75 mm) according to its effect on discharge. The classification is based on own observations for the lower classes (<25 mm) and on a study about flood risk at the reservoir's tributaries (DRPE 1988) for the upper classes. Below 5 mm usually all precipitation evaporates. Discharge is initialized by 5-10 mm. For higher daily precipitation the flood risk is weak (<25 mm), medium (25-50 mm), high (50-75 mm) or very high (<75 mm). Since the available data starts between the 1963 and 1982, no averages were calculated and the cumulative sum of all classes is plotted for each station.

Annual inflow sums into the reservoir Mansour Eddahbi was normalized (1940-2003). For the period 1998 to 2003 the daily inflow was divided in two classes of magnitude according to normal base flow and floods. Finally, the number of flood days per hydrological year was calculated.

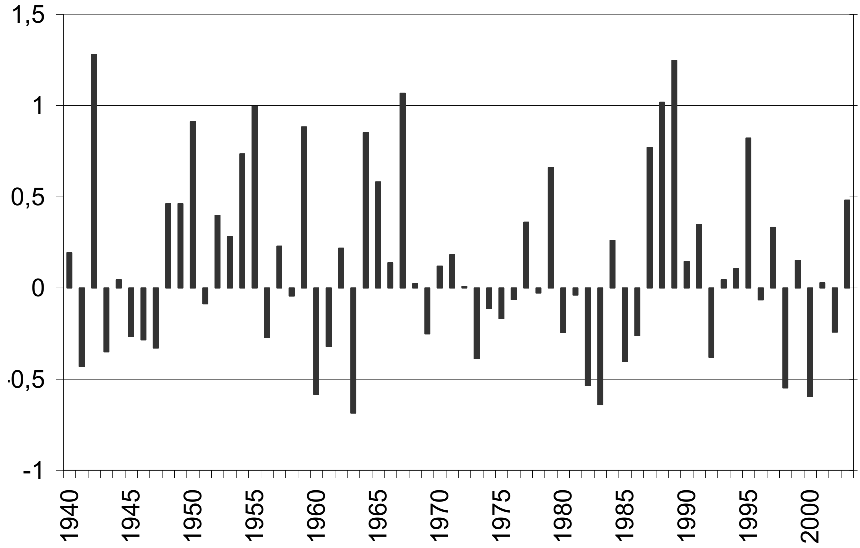

Fig. 2.6.2. Normalized average of the annual precipitation sums at the stations Ouarzazate, Ifre, Ait Mouted and M'Semrir (1940-2003).

2.6.2 Results

Decadal variability of annual precipitation sums

There is highly variable development of precipitation sums at the long time recording stations of the Upper Drâa region (Fig. 2.6.2). Although the variability at and between the stations is high (Fig. 2.6.3, Table 2.6.2), it can be seen that they coincide in the presentation of clusters of drier and more humid years with a persistence of three to seven years. More humid periods can be identified for the late 40s to the mid 50s, the mid 60s and the late 80s. Periods of drought were the early 70s, the early 80s, and the late 90s to the beginning of the new millennium. The decades between the late 40s and the late 60s were wetter than the period before and wetter than the last 30 years before today with exception of the late 80s. Besides this non-linear characteristic, neither a clear cycle nor a clear trend can be seen so far within this highly variable evolution (standard deviation >50%). For example, Knippertz (2003) found positive precipitation index values for the south Atlas region beginning in the 1980s. Then again, the drought of the last ten years has been interrupted by single years with roughly normal precipitation amounts. These observations are important for the discussion of water availability from the reservoir.

Comparing these results for the regional data base with findings at the larger scale of the south Atlas region identified by Knippertz (2003), it can be concluded that the additional data supports the known facts of the decadal variability of pre-

Table 2.6.2. Averages of annual precipitation sums and standard deviations at measuring stations for different record lengths (data provided by the DRPE Rabat and the Service Eau Ouarzazate). For locations and description cp. Table 2.6.1.

Station	1940-2003		1975-2003	
	Annual precipitation (mm)	Standard deviation (mm; %)	Annual precipitation (mm)	Standard deviation (mm; %)
Agouim			244	134 (55%)
Ait Mouted	181	90 (50%)	161	81 (50%)
Amane-n-Tini			100 (1982-2003)	61 (61%)
Assaka-Tafounante			117	69 (59%)
Ifre	171	89 (52%)	165	95 (57%)
Ouarzazate	117	62 (53%)	113	60 (54%)
Tinouar			105	55 (52%)
M'Semrir	223	102 (46%)	221	84 (38%)

cipitation as the main climatic characteristic. Furthermore the variability at the smaller regional scale of the stations under research in this study shows the difficulty in defining one station as representative for a region.

Precipitation intensities

The precipitation intensities in the study area are calculated on the base of daily data which is available for most stations in the Upper Drâa basin since the beginning of the 1960s. The stations, included in the following analysis, are: Ifre, Ait Mouted, Amane-n-Tini, Assaka Tafounante, Tinouar and Agouim. The locations of the stations cover most of the study area. Only the extreme western part and the central northern part are not represented well since the locations were selected for discharge measurements of the reservoir's main tributaries. Daily precipitation sums at each station were classified into six classes according to the amount of precipitation. Thresholds were chosen at 5 mm, 10 mm, 25 mm, 50 mm and 75 mm (Fig. 2.6.3). A change of intensity would give reason to suspect a change of the local or regional climate system.

The time series of cumulated precipitation intensities for each year at the mentioned stations show that in most cases high annual precipitation sums originate from an increase of moderate to high precipitation rates. Therefore a single year is more characterized by the sum of few high daily precipitation events than by the accumulated precipitation of days with less than 25 mm. The result for all investigated stations is that the redistribution of precipitation to classes of intensity does

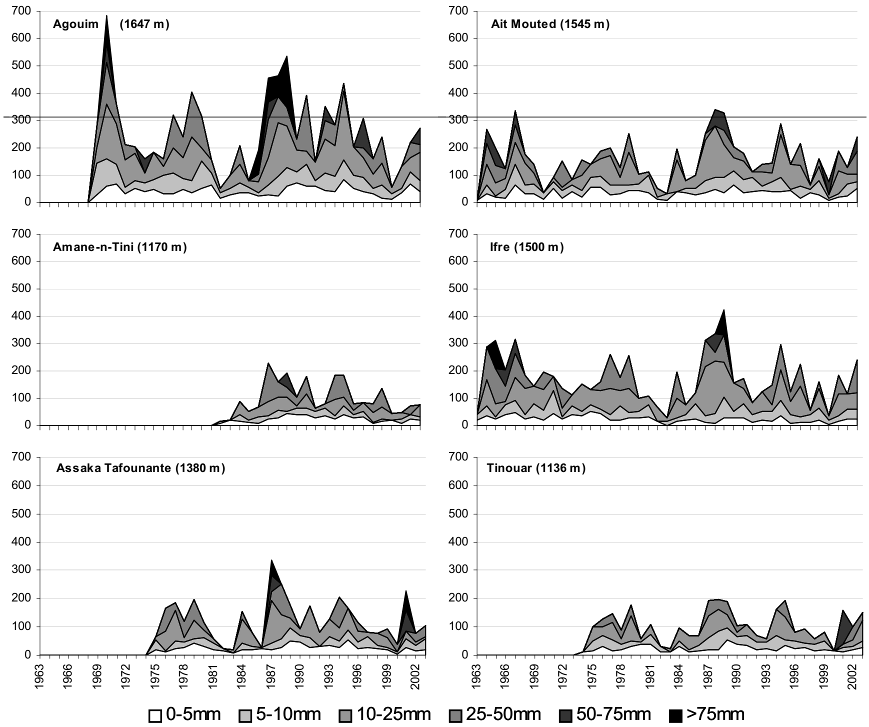

Fig. 2.6.3. Precipitation intensities and annual cumulative sums at the stations Agouim, Amane-n-Tini, Assaka Tafounante, Ait Mouted, Ifre and Tinouar.

not indicate a trend during the last forty years. At all stations the annual variability covers a slight change if there is one. This outcome repeats the facts of the analysis of annual precipitation sums.

It can be concluded from these findings that there is no regional trend in precipitation sums or intensities but a decadal variability with drier and more humid periods.

Decadal reservoir inflow variability

Water availability in the urban area of Ouarzazate and in the Middle Drâa Valley depends highly on the refill level of the reservoir Mansour Eddahbi. Since the initially planned annual volume for irrigation (250 Mio. m^3; Pletsch 1971, Riser 1973) of the six oases downstream of the reservoir was not available during the last decade of predominant drought, groundwater extraction has increased remarkably, which led to a decline of groundwater levels (Klose et al. 2007). It could be shown

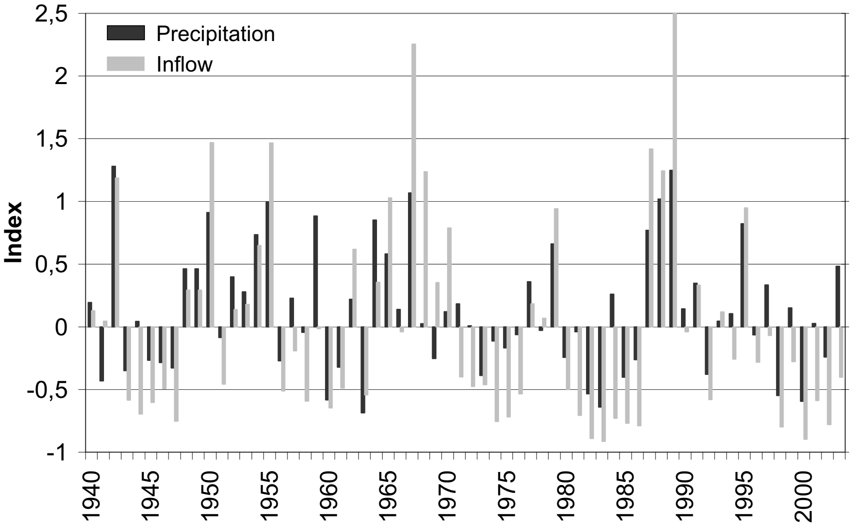

Fig. 2.6.4. Normalized inflow into the reservoir Mansour Eddahbi and normalized average of the annual precipitation sums at the stations Ouarzazate, Ifre, Ait Mouted and M'Semrir (1940-2003).

in the previous chapters that the rate and intensity of precipitation in the region does not follow a trend but has been highly variable during the last decades, thus the inflow into the reservoir followed this pattern.

In Fig. 2.6.4 the annual inflow is indexed to the average of the whole time series (1940-2003) and compared to the index of average precipitation at the stations M'Semrir, Ait Mouted, Ifre and Ouarzazate, which represent the centre and the eastern part of the Upper Drâa basin.

The annual inflow amounts (average: 409 Mio. m^3) correlate satisfying with the mean precipitation (R^2=0.67).

Results of climatological modelling for the Drâa region (Speth and Diekkrüger 2006) predict a slight decrease of overall precipitation and change to more extreme rainfall events. To estimate the consequences of this assumption we analysed the inflow into the reservoir on daily basis (1997/98 to 2002/03). This allowed taking into account the redistribution of two types of inflow, notably perennial basic inflow (low flow) and flood events. The threshold between low flow and floods was set to 10 m^3/s since the main tributaries to the reservoir add to approximately 10 m^3/s (Oueds M'Goun, Dadès and Ouarzazate). Fig. 2.6.5 is based on measurements and water balance calculations. The water balance of the reservoir in the hydrological years 1997/98 to 2002/03 characterizes the water availability: two

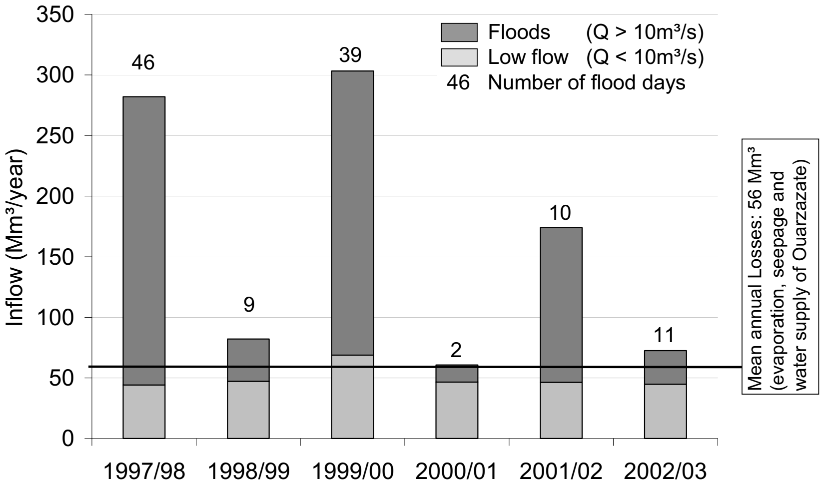

Fig. 2.6.5. Annual inflow sums into the reservoir Mansour Eddahbi and number of flood days for the hydrological years 1997/98 to 2002/03, calculated from daily data. In 1997/98 only eight months and in 2002/03 ten months were available.

years clearly below average, one year of relative and three years of severe drought. The initially planned annual water supply for the Middle Drâa Valley of 250 Million m^3 was clearly out of reach in the years of drought.

Regarding the low flow conditions, it can be summarized that only 50 Million m^3 contribute to the water balance, which is in the same magnitude than the mean annual losses through evaporation, seepage and water supply of Ouarzazate. In humid years the low flow represents 20% of the total inflow whereas in the years of drought it aids with 60 to 80%. This underlines the importance of the High Atlas Mountains with its higher precipitation, notably from snowmelt and groundwater recharge (Schulz 2006, Schulz and de Jong 2004, Cappy 2006) to overcome periods of drought.

2.6.3 Perspectives

The consequences of a climate change scenario according to the IPCC (2001) for Morocco were discussed by Benarafa (1992). An augmentation of temperatures in the magnitude of 3° C until 2050 would increase the potential evaporation about 200 mm per year, a rising of the altitudinal limits of agriculture, but also an acceleration of desertification phenomena. The implications of livestock management, arboriculture and tourism were explored by Parish and Funnell (1999). They found that there will be a need to change tenure conditions and other rules of management.

According to Maselli (1995) the variability of precipitation and the frequency of dry years have increased in the Western High Atlas during the last 30 years. The proportion of heavy rainfalls in wet years also appeared to have increased in that region. This could not be found for the Central High Atlas to the present state.

Scenarios of climate change in the south atlas region (Speth and Diekkrüger 2006) imply an increased warming of the atmosphere through rising greenhouse gas concentrations. Increasing snow lines of about 200 m in altitude (from 2000 to 2200 m a.s.l. in general, with high variations between snowfall events) are expected to enlarge the portion of liquid precipitation. The Drâa basin as part of the South Atlas region is generally influenced by low pressure activity of the mid-latitudes during the cold months and by tropical-extratropical interactions from areas south of the Sahara. According to these two main processes leading to precipitation, different scenarios were developed. In the scenario of a shifting northwards of the North Atlantic Oscillation activities reduced precipitation is expected in the High Atlas Mountains whereas the basin of Ouarzazate experiences less but more intense rainfall events. According to IPCC (2001) the North Atlantic Oscillation is a key factor in Moroccan climate vulnerability. In the scenario of an enhanced humidity advection caused by rising temperatures, an augmentation of winter precipitation is expected, with more intense events in the High Atlas (Speth and Diekkrüger 2006). The predicted increase of extreme precipitation events causing floods in the future is assumed to deliver more water to the reservoir than today. Rising temperatures continue the trend to less snow in winter which in that case falls as rain and increases the direct and interflow. The snow storage would be reduced and the time lag between snowfall and melt is shortened. Since it was shown that floods play a major role in refilling the reservoir Mansour Eddahbi, it has to be further investigated whether a slight decrease of annual precipitation sums can be compensated through less frequent but more intense rainfall events in the Upper Drâa basin. Siltation of the reservoir which is an already known problem in Morocco (Lahlou 1988) will increase under these circumstances. The current and future water availability in the Drâa region is subject to ongoing research within the cooperation of the Moroccan administration and the IMPETUS project.

Acknowledgements

We would like to thank our colleagues at the DRPE Rabat and at the Department of Geography, University of Bonn for the support of our climatological and hydrological work. The Office Régional de Mise en Valeur Agricole de Ouarzazate (ORMVAO) provided additional data and reports. The staff of the Service Eau de Ouarzazate helped during field work with discussions, transport and data. Both administrations are thanked for their support.

Responsible for the IMPETUS automatic weather stations monitoring network is the climatology group (Winiger, Loeffler) at the Department of Geography, University of Bonn.

This work was supported by the Federal German Ministry of Education and Research (BMBF) under grant No. 01 LW 06001B and by the Ministry of Innovation, Science, Research and Technology (MIWFT) of the federal state of Northrhine-Westfalia under grant No. 313-21200200.

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