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PHYSICAL GEOGRAPHY OF THE COUDE DU DRA REGION

Abstract: Situated on the border between the AntiAtlas and the Sahara Desert, the Coude du Dra was chosen for this study because of its great diversity of natural environments that influences the lives of the local population. The environment owes its variety to the geological and relief structures and to the transitional character of the climate. Depending on the season the region comes under the influence of either Mediterranean or very dry climates. The consequences of this transitional character are discussed further in the paper.

Key words: AntiAtlas, Coude du Dra region.

1. Investigation area

The area investigated is situated in the Coude du Dra region in South Morocco near the Algerian border (Figures 1, 2). In the north it is bounded by the monoclinical ridge of Jebel Bani rising to 1456 m a.s.l. Jebel Bani is a part of the Anti-Atlas and is a typical cuesta with a steep slope exposed to the North and a gentle southern slope (Figure 4, Photos 1, 2). The southern slope is strictly determined by the position of the bedrock (Photo 2). The ridge is dissected by various intermittent river channels that are short on the northern slope and longer on the southern slope. In the south the research area is bordered by the edge of the wide stony plain of the Hamada du Dra rising up to 770 m a.s.l. The Hamada du Dra is on the Algerian side of the border. The episodic Iriqui Lake (Figure 2) is the western border of the research area and the eastern border is formed by a side ridge of the Jebel Bani–Beni Selmane range and the Mhamid oasis. Mhamid is the biggest town in the area with 2000 inhabitants (Figure 4).

The Coude du Dra is a flat area situated 550 m a.s.l. in its eastern part and at 450 m a.s.l. in the west (Photo 3). The broad valley of the periodic Dra river is situated in the middle of the research area (Figure 4, Photo 4). The headwaters of this

river are situated 400 km away, on the southern slopes of the High Atlas. The river is the main water course in the area discussed.

2. An outline of the geology and relief of the area

The analysis of the geological map of the region (Figure 3) shows that the Coude du Dra area and its surroundings are mainly formed of Palaeozoic, Devonian and Ordovician rocks that are monoclinaly inclined towards the south. The top part of Jebel Bani is built of Ordovician sandstones, quartzite sandstones and grey-green clays. Within these formations dolerite intrusions locally occur as dykes and sills (*Carte Géologique du Maroc* 1989). This area is thus built of very erosion-resistant rocks as well as rocks that are not resistant to erosion which is why the relief of this area is so varied. The rock layers of Jebel Bani, which were originally in the main horizontal, were folded as a result of the Tertiary elevation of the AntiAtlas. Intense erosion activity in pluvial periods caused erosion of the non-resistant rocks. The material was transported to the Jebel Bani foreland and accumulated as alluvial fans thus forming the Dra highlands. At the foot of Jebel Bani the remains of five levels of accumulation terrace or depositional glacis occur. They are as follows:

- The lowest terraces of the postglacial Rharbien pluvial period with the youngest sediments, usually silt and glacis covered with young sediments;
- Low terraces of the Soltanien pluvial period. The Soltanien period is the equivalent of the European Würm glacial period (Coque 1977);
- The middle terraces of the Tensftien pluvial period (equivalent to the Riss glacial period and the Riss/Würm interglacial period) and depositional glacis and alluvial fans of that period;
- Older terraces of the Amirien period (Mindel glacial period and the Riss/Mindel interglacial period in Europe) and the depositional glacis and alluvial fans of that period;
- Oldest terraces of the Saletien period (the equivalent of the Günz glacial period and the Günz-Mindel interglacial period in Europe), depositional glacis and the alluvial fans of that period.

Wide alluvial plains formed during more humid climatic conditions are called “feija”. The ridges and especially the twin-synclinal Jebel Bani ridge, are built of solid and resistant rocks, mainly quartzite sandstones. They divide three feijas – the long Fezouata in the north, the considerably smaller Ktaoua situated in the Tagounite area and the third feija in the Mhamid area (Figure 3). Feija Fezouata stretches from Foum Zguid to beyond Zagora. Feija Ktaoua is a basin-like area running along the N-S axis and reaching its widest point in the Tagounite area. The third low-area consists of considerably less-resistant Silurian shale in front of Jebel Bani. This area around Mhamid is located to the south of the oasis and passes into Feija Tazzarine-Tarnbalt (Joly 1962) and, in the west, into the Coude du Dra region (Figure 3).

In the south the alluvial Coude du Dra plain is adjacent to Hamada du Dra (Jebel Quarkziz) built of Devonian rocks, mainly limestone. The geology and relief of this area are very similar to other Moroccan hamadas. The top part of the hamada

is characterised by a rather uniform relief of little diversity. It is delimited to the north by a very clear cuesta formation that divides it from the plain. There is a series of residual hills, including Glib, Zegdau, El Azig, Gour Idergane, Garete Khadem, formed as a result of intensive denudation processes on the edges of the Hamada du Dra's structural surfaces.

The research area – the Coude du Dra depression – is situated between Jebel Bani and Hamada du Dra and is covered with alluvial, mostly Pleistocene and Holocene material that had been accumulated as alluvial fans or terrace surfaces formed in pluvial periods by the Dra river (Alimen 1957a, 1957b). Today, the area features a variety of aeolian forms, such as barchans, barchanoidal dunes and sand fields (Photo 5). The dunes reach up to 111 m above the surrounding area. The only duneless area is the wide river channel of the Oued (Wadi) Dra that can be characterised by a wide braided gravel bottom and multi-river channel.

3. Climate

The location of the study area behind the Atlas mountain ranges begs the question as to what extent the climate and, consequently, the hydrology of the area discussed depends on these mountain ranges?

Analysing climate one has to consider also at least the climate of the southern High Atlas as the sources of the Dra river are situated there. In this context the climate of the AntiAtlas is important only in consideration of Jebel Bani's southern slopes as most of the periodic rivers run southwards. The amount of precipitation in the area investigated, and especially in the Dra river drainage basin, greatly influences the river flow and the ground water level in the area discussed.

To provide a full picture of the climatic conditions and their influence on the area investigated, the broad territorial characteristics of the chosen climatic conditions, influencing the research area both directly and indirectly were provided.

The climate of the area discussed is arid-continental. In summer this area is under the influence of the Sahara low pressure belt (or of its northern borders). This situation can be characterised by the occurrence of precipitation caused by a southward movement of the westerly wind zone that carries humid air masses from the Atlantic. Yet the precipitation occurs very rarely because of an orographic barrier (the Atlas Mountains) preventing the air masses from moving inland. In summer, the rain-carrying wind is replaced by the south-westerly trade wind. This wind is a strong drying factor of the Mhamid oasis area as well as of the whole region investigated which is not orographically protected. Precipitation only occurs during cyclonic synoptic situations. These phenomena have a wide vertical range and that is why the humid air masses can cross-over the south-western part of the High Atlas moving inland. The precipitation takes place mainly on the southern slopes of the AntiAtlas but part of the humid air masses carrying rain does reach the oasis of the Dra river valley, including the area discussed.

Precipitation patterns characteristic of the whole area of the northern extremities of the Sahara Desert in Morocco, Algeria and Tunisia is very differentiated, both

in seasonal and annual or multi-annual scale. This complex character of precipitation characterises both the area investigated and the mountain regions situated further north (Figure 5). For the Tagounite meteorological station situated 600 m a.s.l. the average annual precipitation is 52.9 mm, maximum – 182.3 mm and minimum – 6.2 mm, which is approximately 30 times lower than the maximum annual precipitation. For the Ouarzazate station, situated near two rivers that give birth to the Dra river at an altitude of 1162 m a.s.l., the average annual precipitation is 117.7 mm, maximum – 274.6 mm and minimum – 24.6 mm (approximately 11 times lower than the maximum annual precipitation). For the station situated on the Tichka pass 2100 m a.s.l., in the highest areas of the Dra river drainage basin, the average annual precipitation is 562.5 mm, maximum – 1025.0 mm, minimum – 200.0 mm (five times lower than the annual maximum). Those results show the increasingly uneven character of the precipitation along the river Dra valley southwards.

Another factor influencing the differentiated flow of the Dra river is the changing character of the precipitation in the upper part of the Dra drainage basin, which is the most important water resource for the river. It is possible to say that the stations situated within the source area, the Imini-Ouarzazate tributary in the north-western part of the Dra drainage basin, show higher precipitation values than stations situated in the north-eastern part of the Dra drainage basin, along the Dadés tributary river.

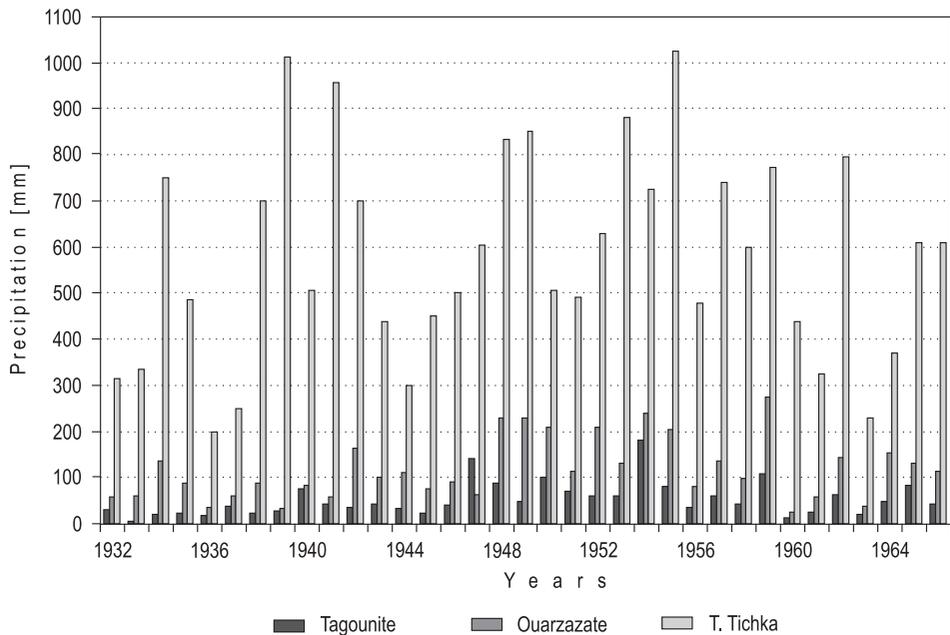


Figure 5. Average annual precipitation totals at Tagounite, Ouarzazate, T. Tichka for the period 1932-1966 (after *Rapp. hydrologique sur la région de l'Oued Dra 1969*)

Considerable variability of precipitation is mostly an obstacle to agriculture and especially the planning of irrigation procedures. The importance of precipitation, its sums and regularity does increase southwards. If no precipitation occurs in the mountains the importance of rain in the south considerably increases because it is the only water resource for the agricultural fields and ground water resources.

During interviews with farmers in the Mhamid oasis, the year 1969 was often mentioned: “in autumn, at the end of October there were two days of rain in the Mhamid region. The fields were flooded and filled with water. Yet during the long local sirocco wind period the soils dried out and the grain dried soon after it emerged. In the High Atlas there was little rain so the river Dra brought little water. At the end of November, however, a little rain fell in the Mhamid area (ca. 3 mm) and it revived the grains.”

Despite such great variability, it is possible to estimate by analysing monthly precipitation sums (Figure 6) that more than half the precipitation takes place in the autumn months. Winter and spring have similar precipitation sums while summer months have very little or no precipitation (Table 1).

Autumn rains are the most important for agriculture. Figure 6 shows two annual maxima: the first from September until December and the second in March. However, the autumn rain period is more important because grain is sown during these months. If the spring rainfall comes late and takes place during harvest time around mid-April, the grain is not fully grown and loses its nutritional value.

Yet another problem occurs when the rain starts too early e.g. at the beginning of September, which, according to local people, happens quite often. Because one cannot be sure when the next rain will fall, sowing should already have been started by then, at the beginning or in the middle of September. However, if the rain does not fall in the latter period, the high air temperature will dry the planted seed and newly grown plants.

If the rain does fall, the plants can grow too fast and pollination will take place during the cold month of January. In both cases the harvest will be reduced.

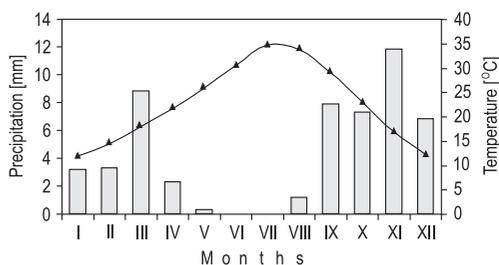


Figure 6. Average monthly temperatures and precipitation totals at Tagounite for the period 1931-1967 (after *Rapp. Dra, 2/IIIA* and *Rapp. hydrologique sur la région de l'Oued Dra 1969*)

Table 1. Average seasonal and annual temperatures and precipitation totals at Tagounite (after *Rapp. Dra, 3/II A*)

Season	Temperature [°C]	Precipitation	
		[mm]	[%]
Autumn	23.0	26	49
Winter	12.9	13	25
Spring	21.8	12	22
Summer	33.0	2	4
Year	22.6	53	100

The precipitation maxima (rain periods) are separated by two dry seasons:

- Winter drought: January-February,
- Summer drought: May-August.

At present, when most of the fields in the oasis are irrigated, this variability of precipitation is not so important any more. Yet one should not underestimate its importance for the hydrology of the region beyond the Mhamid oasis. In the areas that have not been flooded by the Dra river for a long time, precipitation lifts the ground water table thus enabling the growth of ephemeral meadow vegetation, which is crucial for the nomadic pastoral economy of the region.

Table 2. Absolute extreme temperatures at Tagounite (1931-1967) (after *Rapp. Dra*, 2/III A)

Month	January		July	
	Min	Max	Min	Max
	-5.2	29.2	18.0	50.2

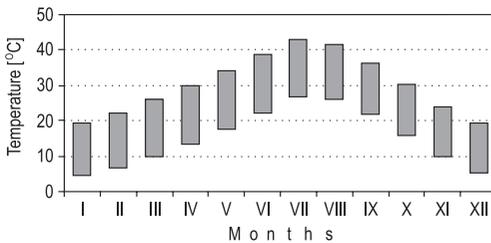


Figure 7. Average monthly temperature amplitudes at Tagounite for the period 1931-1967 (after *Rapp. hydrologique sur la région de l'Oued Dra 1969*)

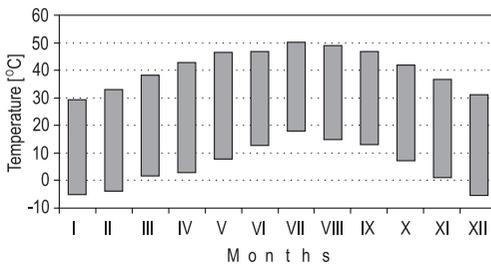


Figure 8. Absolute monthly temperature amplitudes at Tagounite for the period 1931-1967 (after *Rapp. hydrologique sur la région de l'Oued Dra 1969*)

The characteristics of air temperature have been described using data from the Tagounite meteorological station (*Rapport Hydrologique sur la région de l'Oued Dra 1969*). The average annual temperature in Tagounite is 22.8°C, which is very unfavourable, both for local people and domestic animals inhabiting the region as well as for the majority of agricultural plants. Only palm trees are well suited for such high temperatures. In the summer season, grain does not withstand high temperatures and this is why no summer sowing takes place. Another reason is the small amount of water available.

In Tagounite the absolute minimum temperature has been observed in January: -5.20°C (Table 2.) while the average minimum annual temperature is approximately -4°C. The average maximum annual temperature within 36 years has been approximately 40°C (Figure 7) with a maximum temperature of 50.2°C (Table 2). The highest temperature has been observed in July.

Extreme monthly temperature can be characterised by big amplitudes with no regard to the season (Table 2, Figure 8). Temperature amplitude in January is 34.4°C, and in July it is 32.2°C. Daily temperature differences are also important in the area studied.

A daily temperature amplitude reaching up to 30°C is very unfavourable both for local people and for agricultural plants. The temperature drop after sunset is especially characteristic. During the night the temperature keeps dropping and it reaches its lowest values in the early hours. Right after sunrise it rises again very quickly.

Evaporation is another climatic factor that influences the environment of the area discussed (Figure 9). Factors influencing the high rates of evaporation that occur in the area are as follows: high temperatures, low air humidity and almost constantly blowing wind. There is no data concerning actual evaporation but it is undoubtedly considerably lower. The most important reasons for this situation are the low precipitation and also the absence of water retention reservoirs. The evaluation of the potential evaporation rates for the study

area is very difficult and the values cited in the literature relating to this phenomenon are very inconsistent. The average annual evaporation for the year 1971 is 3369 mm (*Rapp. Dra. 2/IIIA*). The potential evaporation at the foot of the Atlas Mountains is approximately 4059 mm according to J. Przybyłek (1993). J. Dubief (1960) estimates evaporation for Tagounite at 2900 mm per year. While one can consider the data given by J. Dubief as much too low, one should consider the value given by R. Capot-Rey (1953b) – 5042.7 mm per year, as much too high.

Wind is considered to be one of the main climatic elements influencing the study area. It is a strong relief forming factor which is especially important for aeolian processes such as deflation and the formation of aeolian accumulation landforms. Wind vastly influences the economy of the region and it has a very harmful influence. It has a variable character in regard to both its strength and frequency and a very stable character with regard to its direction. There are two periods with a higher frequency of wind occurrence: first between the summer and autumn seasons and second between the spring and summer seasons. One should also note that a north-east wind prevails in the summer period as the study area is under the influence of trade winds. Two types of wind have an especially negative influence on the region's agriculture because of their drying nature:

- Chergui (eastern wind),
- Sirocco (southern wind).

If this kind of wind continues to blow for a longer period of time all the agricultural fields can dry out. After three days of Chergui a freshly watered field is already totally dry and it must be watered again (Information obtained from farmers in the Mhamid area). Other effects of this wind are: premature ripening of the grains or their premature drying. Both these effects cause considerable losses in crops.

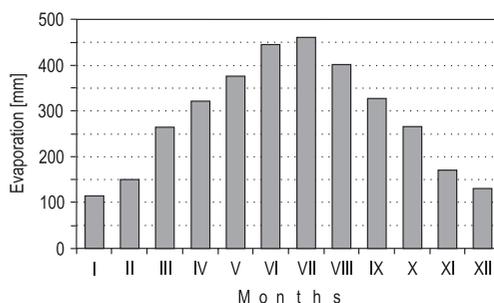


Figure 9. Average monthly potential evaporation at Tagounite for the period 1931-1967 (after *Rapp. Dra, 2/IIIA*)

What is more, this kind of wind causes sand storms influencing the everyday life of the local people, making breathing more difficult, impairing visibility etc. Sand storms are also a cause of the sand dune mobility which endangers communications and irrigation systems etc. Mobile sand covers houses and other buildings and also agricultural fields in the Mhamid oasis (Photo 6). Mobile sand enters the oasis, travels between the houses and covers gardens and orchards. Dunes up to several metres high can be formed within the oasis. The movement of sand dunes also affects other regions on the northern boundary of the Sahara Desert and causes negative changes in the natural environment (Dłużewski 2000).

4. Characteristics of surface and sub-surface water

The river system of the area was formed during the pediplanation process that took place in the Oligocene period. At the time, rivers (including the Dra river) ran across an area which was the subject to tectonic movements related to the Alpine folding. Rivers accumulated alluvia on the southern foreland of the AntiAtlas. In the Pliocene period, almost all the rivers originating in the AntiAtlas supplied the great "hamada lake". The elevation of the AntiAtlas in the Plio-Villafranchian period put an end to this balance. The bottom of the lake had been deformed and in consequence of this the water level dropped and the lake eventually dried out. In the area of the lake a river had been formed flowing from the AntiAtlas towards the Atlantic Ocean. This period can also be characterised by an increasing river channel depth as a result of the domination of erosion processes over accumulation. Intense orogenic movements that are responsible for this process led to the rivers cutting into the Precambrian formation and thus the shaping of the contemporary river channels of this region (Ambroggi, Choubert 1952)

The Dra river is currently formed from two large rivers originating in the High Atlas Mountains, the Imini-Ouarzazate River and the Dads River. The Dra drainage basin covers 13500 km². The Dra river runs through the AntiAtlas Mts. along a NW-SE axis forming a gorge in Precambrian formations. Then the river reaches the pre-Sahara region near the town of Mhamid. Between the oasis of Ktaoua and Mhamid the Dra river forms an elbow bending west towards the ocean, which it reaches after running through the desert for 600 km. A characteristic feature on the course of the Dra River is Iriqui Lake, a wide basin with a flat bottom that is filled with water only occasionally

Due to the hitherto described climatic conditions and especially the small amount of precipitation, the surface and sub-surface waters of the region are primarily influenced by the Dra river water carried from the Atlas Mountains. The number of rivers ending in this region is very large but one has to consider the periodical character of those rivers. The wide dry river channels were formed when the climate of the region was much more humid with much more precipitation. Those river channels are only filled with water during the periods of heaviest precipitation and only then do they have a major importance as a water resource for the ground water resources.

After heavy rains in the Atlas Mountains its rivers have very high discharges. Prior to the erection of the Mansour Eddahbi dam, the discharge in the Oued Dra at Agdez ranged from $0.1 \text{ m}^3 \cdot \text{s}^{-1}$ during dry periods to a record $5300 \text{ m}^3 \cdot \text{s}^{-1}$ after the heavy rains of 1949. Huge volumes of channel rubble can be displaced during this type of discharge. The average annual discharge of the Dra at Zagora varies greatly between the average of 100 and 300 million m^3 . The recorded figures show an even greater difference from 68 million m^3 per year to 1800 million m^3 per year (www.water.gov.ma). The Oued Dra area of Mhamid rarely sees water flowing due to high rates of evaporation, upriver irrigation systems and oued-bottom infiltration.

Based on the above mentioned precipitation characteristics, two periods of maximum runoff can be observed for the Dra river, firstly in November connected with the high precipitation in autumn and secondly usually in March or April. For the Tagounite station the runoff can be up to $40\text{-}48 \text{ m}^3 \cdot \text{s}^{-1}$ and in some cases (e.g. in 1949 and 1956) it was even $100 \text{ m}^3 \cdot \text{s}^{-1}$. According to information collected from local people one can assume a very stable runoff taking place over a whole month while after local storms it takes place for only a few days or up to a week. Two periods with the highest runoffs can be compared with two periods with the lowest water levels. These occur in winter (December, January) and even more pronouncedly in summer (June-August). In Tagounite the runoff of the Dra river is then approximately between $22 \text{ m}^3 \cdot \text{s}^{-1}$ in November and $2 \text{ m}^3 \cdot \text{s}^{-1}$ in August (Margat 1958). Water reaches Mhamid only through irrigation canals (Photo 7) while the natural Dra river channel is totally deprived of water, especially in the summer period.

Considerable variability of the average annual precipitation results in the river flow also being variable. The year 1937 is a good example for this relationship. In that year the total runoff in Tagounite was 70 million m^3 per year which corresponds to an average annual runoff of $2 \text{ m}^3 \cdot \text{s}^{-1}$. In 1948 the Dra river carried almost 900 million m^3 of water within a year which corresponds to an average of $30 \text{ m}^3 \cdot \text{s}^{-1}$ over a year (Guitonneau 1952). In periods of extreme flow in the years 1948/49, 1956, 1966, 1980 and 1991, the waters of the Dra River reached the Atlantic Ocean.

Upriver of Mhamid a 200 km long middle-course of the Dra valley features a dam system with the crucial structure of the Mansur Eddahbi Dam south of Ouarzazate. The dam can retain 415 million m^3 per year, while all of the remaining dams in the middle-course of the Dra River are estimated to retain 30-40 million m^3 per year overall (www.water.gov.ma). The Mansur Eddahbi Dam was erected in 1972 and contains nearly half of all the water of the Dra. The dam is 70 m high, 238 m wide and its hydropower station generates ca. 20000 MWh per year. The lake has an area of 45 km^2 and a maximum capacity of 529 million m^3 (its regular capacity is 445 million m^3) (www.water.gov.ma). Its erection stabilised the discharges downriver of the dam and helped irrigate 26000 hectares of fields along the middle-course of the river. There are six natural irrigation systems (Mezguita, Tinzouline, Ternata, Fezouata, Ktaoua and Mhamid) supplied by four main dams (Agdz, Tansikht, Ifly and Azaghar). The engineering projects, however, considerably reduced water available at Coude du Dra and the irrigation systems can now provide a maximum of 23 million m^3 of water

into the Mhamid oasis (www.water.gov.ma), which may be cut several times in dry years. In the area investigated there are two periodic lakes: Iriqui lake, approximately 80 km², and the remainings of the big „hamada lake”. This is situated in the western part of the area investigated. This has been dry since 1995 and water has only accumulated in the subsurface formations at a depth of around 5 m. After the heaviest of rainfalls, the lake receives water from minor oueds running from the northern range of Jebel Bani. The lake bowl has also been shrinking due to mobile sand activity from the El Mhazli, Abilia and Hajhamed ergs.

The periodic lake Arhbaro (ca. 20 km²) is situated in the south-east part of the research area. Only a few small and periodic rivers provide water for the lake. All the rivers originate on the northern slope of the Hamada du Dra. The lake area is also subject to intense deflation processes.

Only 56 million m³ per year of ground water is utilised in the Dra’s middle course, of which 30 per cent is accounted for by natural outflows. In the Mhamid area only 9.1 million m³ of ground water per year is used (www.water.gov.ma), from both deep-water-bearing layers and more shallow ground waters in terraces and alluvial fans down to 15 m below the surface. In some deep oueds erosion tends to cut into the water-bearing layers leading to water seeping into the alluvia or even onto the surface. In the northern part of the study area, near Jebel Bani I and II, the local nomadic population taps into quartzite sandstone water-bearing layers of low capacity (ca. 0.6 m³ per year according to (www.water.gov.ma), but crucially of low salinity. There are a series of natural and artificially deepened water abstraction points at the foot of the Jebel Bani range, including Oum Laaleg and water wells at the Tansist locality.

In the river channels and basins filled with alluvial material there occur shallow ground water horizons with a great variability in the water table (Photo 8). The Dra river forms the biggest subterranean flow that provides water for irrigation in the Dra River valley up to the town of Mhamid during the dry period. The capacity of these waters is estimated at 13.2 m³ per year (www.water.gov.ma). The flow is restricted by sandstone and quartzite structures, which elevate the ground water table rendering this resource useless for irrigation purposes. The point where the Oued Dra crosses the Jebel Bani marks the beginning of the area supplying the Mhamid oasis. The local alluvial water capacity is just 1.6 million m³ per year. Downriver from Mhamid the alluvial plain broadens to ca. 20 km and the alluvia are between 20 and 25 m thick. The highly varied alluvia include a dominant sand and clay with thinner layers of gravel and boulder fractions, where the subterranean flows are channelled.

In 1967, the groundwater table was 2 m below the surface within the Dra valley and up to 3-8 m deep at the perimeter of this area (*Rapp. Dra, 3/II 1*) (Photo 8). Records taken in the springtime in 1999, 2001, 2005 and 2006 (including measurements in abandoned or sporadically used water wells), i.e. at the time of peak discharge of the river Dra, definitely suggested a lowering of the ground water table in the alluvial parts of the valley. In a water well located in the Dra valley (well 1) (Figure 2) which was tested, largely supplied from surface water infiltration, the ground water table was determined at 12 m below the surface level. This seems to be a consequence of the upriver river training, and the erection of the dam below Ouarzazate. Between 1999

and 2006, water tables dropped in wells (2, 3, 4, 5, 6) (Figure 2) tested in the northern part of the area: well 2 from 7.2 to 8.5 m below the surface; well 3 from 4.6 to 5.7 m; well 4 from 3.5 to 4.2 m; well 5 from 7.05 to 8.1 m; and well 6 from 2.05 to 2.75 m below the surface. The values are also comparable with those from 1967 (*Rapp. Dra*, 3/II 1), which would suggest that the ground water table in the northern portion of the study area did not fundamentally change and permits one to conclude that the water supply from low-lying water-bearing layers does not change very significantly.

According to the latest data (www.water.gov.ma), overall water consumption in the Dra river basin stands at ca. 517.4 million m³. This includes 406.2 million m³ of surface water used only for irrigation purposes and 110.2 million m³ of ground water of which 88% is used for irrigation and only 13.2 million m³ per year is used for household purposes. It is also estimated that there is a ca. 100 million m³ deficit in water needed for irrigation of the existing farming areas.

The limitation of a horizontal water exchange is one of the dominant reasons for salt accumulation. The salinity of alluvial water is much higher than in waters of the deeper water-bearing horizons. It increases along the Dra river valley and it is highest below Mhamid (max. 18 g·l⁻¹, min. 1.5 g·l⁻¹, annual average: 5 g·l⁻¹) (*Rapp. Dra*, 2/III B). The water used for irrigation in the Mhamid oasis mainly (75%) comes from irrigation systems supplied by the surface waters of the Dra river. About 26% comes from draining the subsurface alluvial water and only 5% comes from wells that are supplied by deeper groundwater horizons (Margat 1958). It is thus possible to assume that the salinity variations in the water used for irrigation are a result of the differences in the flow of the Dra river. It has to be mentioned that the concentration of salt in water used for irrigation is one of the dominant factors influencing the soil quality and in consequence the agricultural use of these soils. Pumping the 15000 m³ of water necessary in these climatic conditions containing 1 gram of salt per litre to irrigate a one hectare field, the soil is burdened with 15 tons of salt per year. Over a period of one hundred years this would produce 1500 tons, or 1/10 of the weight of the soil within reach of the root systems (*Rapp. Dra*, 2/III C).

5. Characteristics of the vegetation

The transitional character of the study area is also expressed in the vegetation of the region. Four vegetation areas can be described according to the occurrence of the „main plants”:

- an area dominated by Mediterranean flora,
- a transitional area between Mediterranean and desert vegetation,
- within this transitional area – an area with vegetation strongly influenced by man,
- an area dominated by desert vegetation.

In southern Morocco, both Mediterranean and desert vegetation occur on a small area. Certain Mediterranean flora species occur almost up to the Sahara Desert (e.g. *Astragalus*, *Reseda*, *Plantago*, *Salsola* and others). These plants can be treated as relicts of the Pleistocene Mediterranean vegetation (Walter 1964) once occurring there (on the area of the Sahara Desert). In these areas acacia trees also occur

(*Acacia raddiana*) (Capot-Rey 1953a). Another Mediterranean species is *Rhus oxyacantha*. Also *euphorbia* occurs (*Euphorbia echinus*, *Euphorbia spinosa* and others) in the transitional area between the Mediterranean and desert habitats.

Within the area of the oasis two types of plant habitat occur: the first is typical of the vegetation of the inner-oasis area; the second occurs in the area close to the oasis used for farming, pasture and cattle breeding. This latter type is also characteristic for the depressions and river channels that are periodic filled with water.

The vegetation of the oasis is primarily composed of palm trees (*Phoenix dactylifera*) and other cultivated crop plants such as: barley (*Hordeum*), wheat (*Triticum turgidum*) and others that are the most important grain plantations in the oasis.

There are also other plants like *Cynodon dactylon*, *Convolvulus arvensis* and a notorious weed *Vicia sativa* (Rapp. Dra, 3/II 1).

Along the periodic river channels there occur: *Imperata cylindrica* and *Saccharum spontaneum* used for basket weaving. The primary vegetation of the oasis composed mainly of *Hyphaene thebaica*, *Acacia albida* and other acacias as well as *Maerua* and *Capparis*, *Calotropis procera* and *Citrullus colocynthis* has been very much reduced (Walter 1964). The primary oasis flora can be found beyond the borders of the oasis in the river channels, where it is used as pasture for the domestic animals of the nomads.

Panicum turgidum (Arab. *Meroubia*) is another plant found in the intermittent river channels and it is a valued animal food. *Aristida pungens* – the dominant species of the so-called „Drin” steppe is used as food for dromedaries and it mainly occurs on sands and dunes and its roots are an important element slowing down the mobile sands in this area (Rikli 1943). There are also other plant species occurring in this area that provide food for the animal world: *Panicum turgidum*, *Polycarpea repens*, *Psorelia pliticans*, *Artemisia herba alfa* (occurring especially in humid depressions), *Bromus rubens*, *Stipa retorta*, *Aristida plumosa*, *Cutandia dihtoma* and *Penissetum dihtomum* (Rapp. Dra, 3/II A).

Tree vegetation is very insignificant and unvaried. The following species occur in the study area: *Ephedra alata*, *Cupressus dupreziana*, *Rhus oxyacantha*, *Hyphene thebaica*, *Populus euphratica*, *Ficus salicifolia*, *Argania spinosa*, *Maerua crassifolia* (Ozenda 1958).

From the 300 known acacia species, four occur in the Dra river valley: *Acacia gummifera*, *Acacia farnesiana*, *Acacia raddiana* and *Acacia albida* (Rapp. Dra, 3/II). Also individual trees of the *Balanites aegyptiaca* (Berb. *Etaichecht*) can be found and also *Cassia lanceolata*, *Cassia obovata*, *Calotropis procera* (Arab. *Coxrouba*; Berb. *Taorja*), *Periploca laevigata* and a few tamarisk species (Walter 1964).

In the area near the oasis and partly even within the oasis itself, a crust is formed on the ground surface as a result of the shallow groundwater table and strong evaporation. The crust is composed of calcium carbonate, gypsum or chlorites and sulphates depending on the salt dissolved in the groundwater. In the southern part of the study area mainly the chlorite crust occurs (Rapp. Dra, 3/II). The following plants dominate in this area: *Salsola*, *Traganum nudatum*, *Zygophyllum album*, *Suaeda* and sometimes *Strobilaceum* and *Salicornia*.

The southern borderline of the study area, the frontier with the Hamada du Dra, can be characterised by a very poor vegetation as compared to the already mentioned areas, which is also suggested in the name of the region (hamada – to die) (Walter 1964). The number of species occurring here is reduced to two hundred (*Rapp. Dra*, 3/II). Green plants are especially rare as a result of the decrease in precipitation. Mediterranean flora elements occur only sporadically (Walter 1964).

6. Conclusion

The Coude du Dra region on the Moroccan and Algerian border constitutes a highly diverse environment making it an extremely interesting subject of natural research, but also a tourist destination. Despite its progressive desertification, the area has been attracting a growing number of tourists who have contributed to its fast rate of development. Near the Mhamid oasis sand dunes are encroaching on houses and fields (Photo 6). Moving sands cover buildings and orchards. Sand dunes up to several metres high develop within the oasis. The area features not just highly variable local climatic conditions, but is also influenced by weather conditions of the high parts of the Atlas Mts. this is why there are very dry periods interspersed by periods with extremely high river discharge. On average every 10-15 years the Oued Dra experiences extreme discharge levels driving huge changes in the valley-bed morphology. Rather than solve local hydrological problems the erection of dozens of dams has exacerbated them. Dammed upriver water cannot reach the Mhamid oasis in sufficient quantity. The place is, however, still exposed to floods during extreme conditions, such as in 1991. Another water-related issue is the restriction of horizontal exchange of waters leading to the increased salinity of alluvial water. This has been gradually increasing along the Dra valley to reach its highest values downriver from Mhamid. Water salinity has a highly detrimental effect on the quality of irrigated soils. In this way, several negative environmental conditions are compounded in a single area. As a result there is a growing deficit of water available for irrigation (Photo 7), which combines with high rates of evaporation to produce an increase in soil salinity and prevent any agricultural activity west of Mhamid. This is also restricting natural vegetation in the area.

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