SAHARA
Co-ordinator

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2.1. SOUTH MOROCCO AND ZEMMUR

2.1.a. LOWER OUED DRA

1. Geography and morphology

29°N, 11°50'W, sea level. Just north of the town of Tan-Tan, a variable area of permanent, mostly stagnant water. Width of the Oued 5-6 m; depth unknown. Floods used to occur in winter or spring, but have now largely been eliminated by dam-building in the Atlas mountains. The water is saline, probably mesohaline for most of the time, and chloride-dominated, but no analyses were available to this author.

2. Geology and climate

The upper Oued Dra descends from the high Atlas into the Western Sahara, makes a westward loop while seeping under the sands, but reappears at the surface as a saline stream in its lower reaches. The lower Oued Dra cuts a shallow canyon through a low plateau composed of Cambrian rock (Hammada du Dra). The very lowest part runs through Quaternary sands. The climate is of the Atlantic Saharian subtype (Dubief 1971). Köppen: BWa.

Average annual irradiation is c. 7.5 $h.d^{-1}$, (more than 10 $h.d^{-1}$ in July). Average solar irradiation 17,000 $kJ.m.^{-2}d.^{-1}$. There is a strong predominance of NE and NNE winds, with relatively little seasonal variation. The strongest winds tend to occur in summer. There are about 300 $d.a^{-1}$ with at least some cloud cover, and 10-15 mist days per annum. Rainfall (c. 50-100 $mm.a^{-1}$) is erratic; maximum during winter.

Mean annual air temperature is c. 19°C, with maximum in September (14-34°C), and minimum in January (5-27°C).

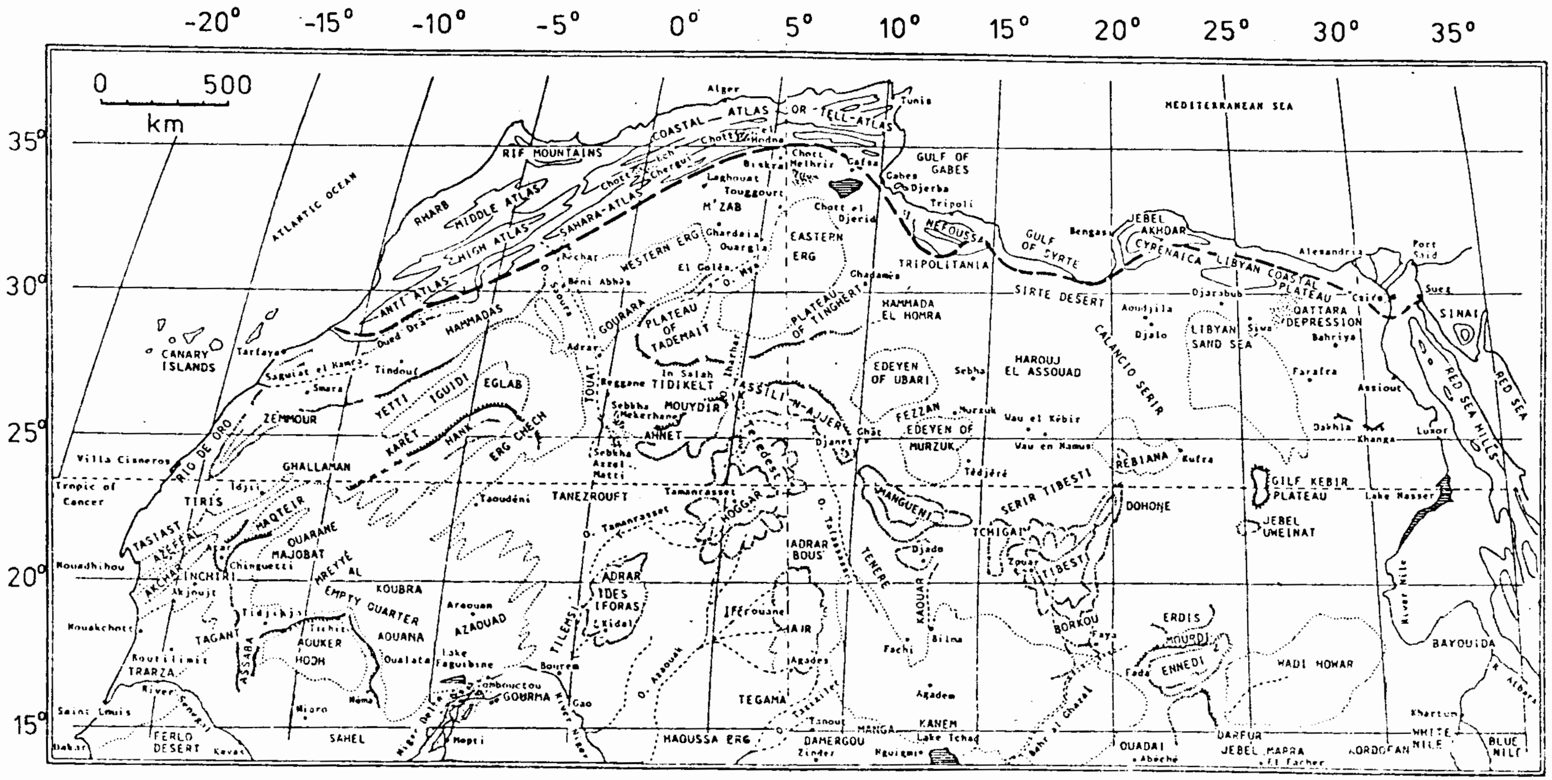

Fig. 2.1 Map of Region 2, Sahara. The broken line indicates the boundary with Region 1, Coastal North Africa.

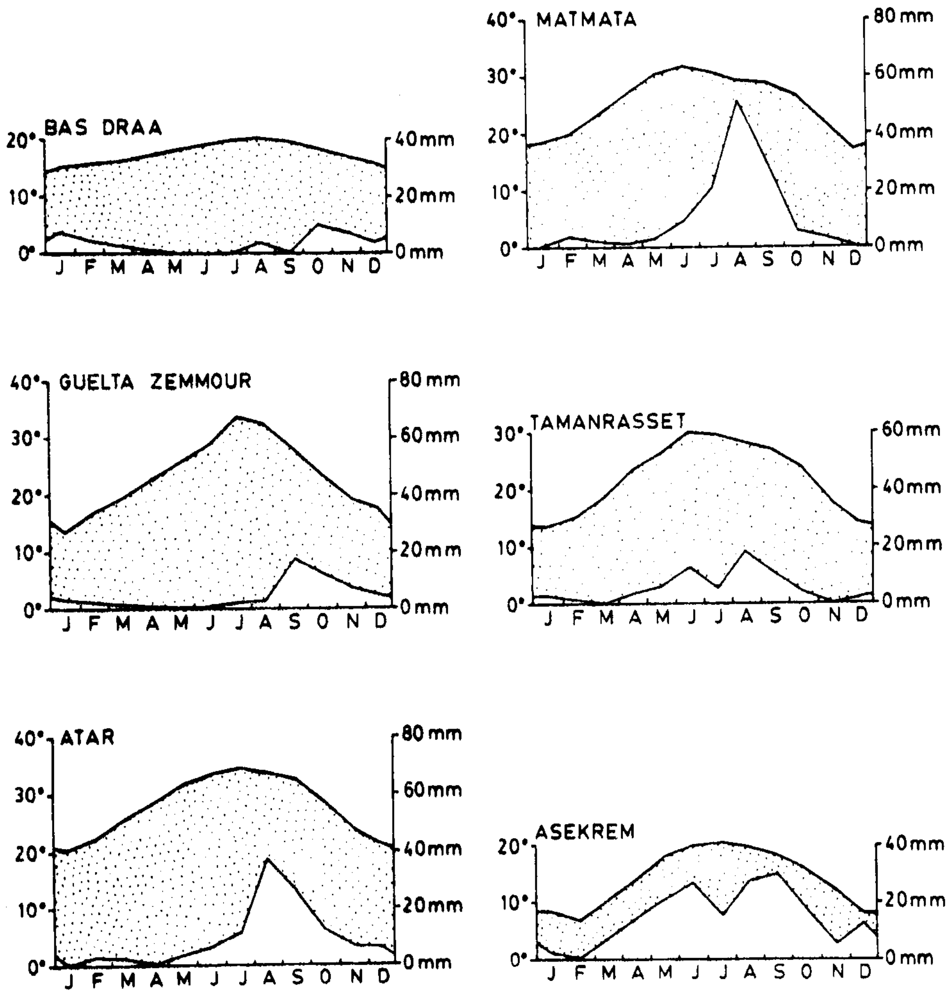

Fig. 2.2 Climatic diagrams for the Sahara

3. **Macrophytes**

Submerged macrophytes have not been observed; filamentous green algae and Enteromorpha are common. The inundation zone is rich in Salicornia; higher spots are covered with Tamarix.

4. **Algae**

Compère (1967) gives a list of 25 species of Cyanophyceae and Diatoms, collected in December 1964.

5. **Invertebrates**

Hydrobia sp. (Mollusca), and shrimps and fairy- shrimps occur. No information on other groups.

6. **Fish**

Fish have been spotted at Tan-Tan, but no species identifications are recorded. Sightings seem to indicate Mugil sp. rather than freshwater Cyprinids or Cichlids.

7. **Human activity:** Human use is almost non-existent.

2.1.b. LOWER SAQUIAT EL HAMRA: SPRINGS OF MESSEIT

1. **Geography and morphology**

In the flanks of the lower Saguiat el Hamra (the "red" canyon), springs are found. The ones at Messeit (27°04'N, 13°09'W) are fairly numerous. Some flow from shallow caves, but most have been diverted into concrete tanks, which are allowed to fill up and are then emptied into a palm tree oasis for irrigation purposes.

2. **Geology and climate**

The canyon is a fossil river valley several km wide and several hundreds of meters deep. In the Messeit area, it cuts through Neogene surface layers overlying Eocene and Cretaceous rocks. The climate is similar to that of the Oued Dra. The average irradiation is slightly higher (c. 18,000 $kJ.m^2.d^{-1}$, with a maximum of 57,000 $kJ.m^2.d^{-1}$) in July.

3. **Water chemistry**

Conductivity was $3600\text{-}4200.10^{-6} S.cm^{-1}$ in April 1975.

Na	K	Ca	Mg	HCO_3	Cl	SO_4
90.0	0.4	8.7	4.8	5.8	35.7	60.0 $meq.l^{-1}$

The water is saline and, in addition to much chloride, contains a remarkably high amount of sulphates.

4. Macrophytes

The irrigation zone is a typical oasis, with date palms and garden cultures. The springs have no macrophytes, but sedges grow in some of the concrete tanks.

5. Invertebrates

The invertebrate fauna has a number of significant species. The gastropods Hydrobia aponensis (Martens), Melanopsis praemorsa (L.), and Pseudamnicola canovula Frauenfeld have been recorded by Van Damme (1984). Among Crustaceans, the Amphipod Orchestia gammarellus (Pallas) was found (Monod, pers. comm.). This is the southernmost record of a surface living amphipod in North African inland waters. Among Copepoda and Cladocera, Daphnia similis Claus, and Halicyclops troglodytes Kiefer should be cited (see Dumont & Van de Velde, 1976). Rotifers (Dumont & Coussement, 1976), Nematodes (Grootaert, 1976), and Oligochaetes (De Henau & Dumont, 1977) are also documented. Among the insects, only dragonflies have been studied. Three species occur, one of which is the desert damselfly Ischnura saharensis (Aguesse).

6. Vertebrates: None recorded.

7. Human activity

The oasis is uninhabited, yet is exploited for garden cultivation. A surfaced road, connecting El Aioun (Lajoun) to Semara, runs nearby and used to bring tourists on visits from the Canary Islands to the oasis. This activity ceased in 1976.

2.1.c. GUELTA ZEMMUR

1. Geography and morphology

The guelta (20°09'N, 12°24'W) is found in an area of rather low mountains, cut by river valleys into a number of shallow gorges of modest dimensions. The canyon in which the guelta is situated has a SW-NE orientation. It is exclusively rainwater-fed and at one time in the 1950's it was nearly dry (Valverde 1957). Refilling occurred as a result of torrential rains. The pool is triangular, with longest side c. 60 m. When the guelta is full maximum depth is c. 6 m. Flood frequency is not documented in the literature, but is probably not yearly. Because of its periodical drying, the guelta is only semi-permanent and thus houses no fish. Because it is periodically flushed out, on the other hand, its water remains fresh.

2. Geology and climate

Rocky outcrops of Devonian age, tilted to an angle of c. 20° at the site of the guelta, are cut through by a small oued. The guelta is in a typical situation, at the foot of a former waterfall (photograph in Dumont & Van de Velde, 1975). The climate is of the Subatlantic Saharian subtype (Dubief, 1971), and Köppen BWa. Mean annualinsolation is 9.5 $h.d^{-1}$. There are about 100 cloudless days per annum, and no mist days. Mean annual solar irradiation is c. 20,000 $kJ.m^2.d^{-1}$, with a mean minimum of 15,000 and a mean maximum 23,000 $kJ.m^2.d^{-1}$. S and SW winds predominate, with highest frequencies in autumn and winter. Seabreeze influence is still present, but of limited importance.

Rainfall (c. 40-50 $mm.a^{-1}$) is rather erratic. Annual mean air temperature is c. 25°C; maximum in August (45-46°C), minima in December-January (down to -3°C) (Fig. 2.2).

3. Water chemistry

Conductivity of $350.10^{-6}S.cm^{-1}$

Na	K	Ca	Mg	HCO_3	Cl	SO_4
1.8	0.1	2.1	0.2	2.0	1.7	0.5 $meq.l^{-1}$

4. Vegetation and algae

No macrophytes occur. Beds of Characeae are found in the littoral. Large colonies of Volvox sp. were abundant in samples collected in spring 1975.

5. Invertebrates

No molluscs are known from the guelta. Because of the absence of vertebrate predators, the zooplankton consists of large species. The Anostracan Streptocephalus torvicornis (Waga), and the large Daphniid Daphnia dolichocephala Sars and Calanoid Neolovenula alluaudi (De Guerne and Richard) abound. Rotifers, Oligochaetes and aquatic Nematodes have also been recorded (see under 2.2).

6. Human activity

Guelta Zemmour is a permanent settlement, and a border-post with Mauretania. It attracts many nomads for trade. The guelta, in 1975, was exploited as a source of drinking water. A cistern truck was in use for pumping up water from the guelta and distributing it around the settlement. Between April and June 1975, the water level had declined by more than one meter, largely as a result of this activity. Pumping ceased in 1976, when Guelta Zemmour became a site of active fighting in the struggle between the Polisario movement and the Moroccan army.

2.2. WESTERN MAURETANIA (Fig. 2.3)

Geology

The deeply dissected Palaeozoic sandstone plateau of the Adrar is very rich in deep, narrow gorges that conserve surface water well. Most gorges empty into wider wadi beds, usually invaded by sand dunes, but their upper reaches provide sites where rain and spring-fed gueltas abound. The gueltas of Molomhar (Oum Lem Har) are found in one of three major E-W oriented canyons that cut through the Tagguel massif, West of the city of Atar. The springs of Terjit, El Berbera and Gueltet Zli are other important relict waters situated in the Adrar. The Tagant is another Palaeozoic sandstone plateau separated from the Adrar by the wide fossil Oued El Khatt. It lies to the SE of the Adrar, and takes a more continental position. Its western part is deeply dissected, hence rich in surface water. The guelta system of Matmata-Tartega is situated at the site where the Oued Ntakech, N-S oriented, close to and parallel with the western edge of the plateau, cuts through a sandstone ridge and empties into the wide basin of the Tamourt-en-Na'aj, one of the two major river systems of the region.

The valley of the Oued Bourraga runs West and parallel to that of the Oued Ntakech and, like it, empties into the Tamourt-en-Na'aj. Its western flank is formed by a sandstone wall, that has two diverticles. The southern one contains the Gamra Ouarbi-Lemzailgue gueltas. The Northern one is the gorge of El Houssiniya.

Lake Le Bheyr is situated at the foot of the NW flank of the Assaba sandstone plateau, a southern extension of the Adrar and the Tagant. It is separated from the latter by the narrrow pass of Diouk and, like the other two, is deeply eroded and dissected by river canyons, rich in waterpoints and with a wide diversity of microclimates.

Climate

The climate of this region is of type BWa (Köppen) but in Dubief's (1971) system that of the Tagant belongs to the northern rim of the tropical transition climate of the Sahara-Sahel. This is evident in the variation in rainfall and temperature seen between the more northern Adrar (represented by data from Atar, Fig.2.2), the Tagant (at Moudjeria) and the more southernly Assaba plateau (as at Kiffa). Mean annual insolation is 9-10 $h.d^{-1}$ and average annual irradiance 22,000-25,000 $kJm^{-2}d^{-1}$. The summer monsoon has a marked effect on the climate of the whole region replacing the usual N-NE trade winds with SW winds which bring most of the rain during June-August. The mean annual rainfall (103 mm at Atar, 140 mm at Tidjikja, 225 at Moudjeria and 350 mm at Kiffa) increases from North to South but its seasonality becomes more marked: in the Adrar some rain may fall in any season but at Kiffa there is normally no rain from November - May yet 120 mm may fall in August alone. Inter-annual variation is also great: in the Tagant between 1931-60 a minimum of 56 mm fell in 1941 and in 1943 a maximum of 405 mm (Toupet 1975).

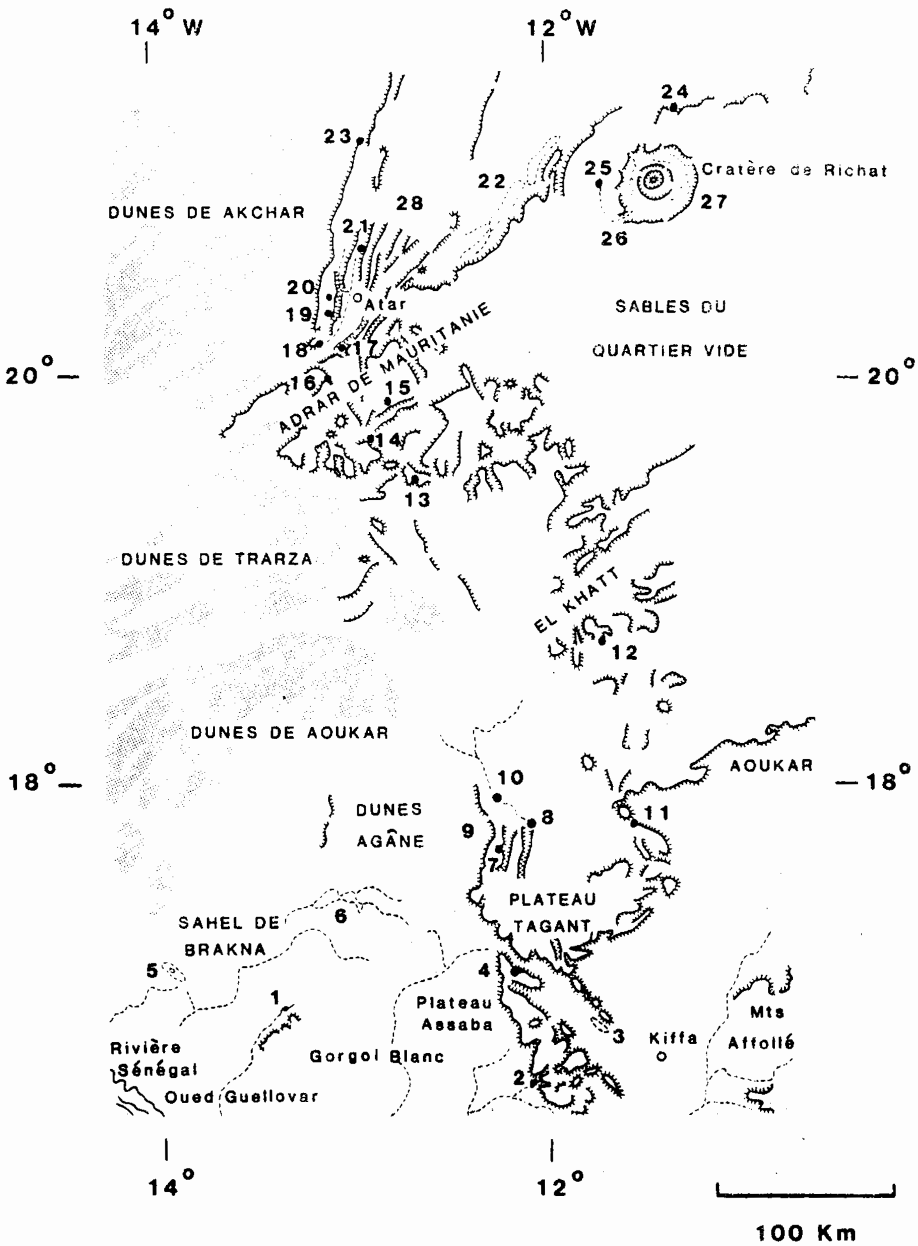

Fig. 2.3 Western Mauretania: locations of the permanent and ephemeral surface waters. 1-Lake Mal, 2-Lake Bheyr, 3-Guerou Marigots, 4-Guelta and Spring of El Ghaira, 5-Lake Aleg, 6-Periodic floodplain of Magta Lagjar, 7-El Housseinye Gamra Ouabi, 8-Matmata Guelta, 9-Achet Spring, 10-Nbeika Marigots, 11-El Gheddia Guelta, 12-Rachid Guelta, 13-Zli Gueltet,14-Glat El Bil, 15-El Berbera, 16-Toungad, 17-Terjit, 18-Hamdoun Guelta, 19-Ilij Guelta, 20-Oum Lemhar Guelta, 21-Tod Spring, 22-Chemchane Sebkhas, 23-Choum Guelta, 24-El Beyyed Spring, 25-Foum-n-Meh Guelta, 26-Ouadane Guelta, 27-Floodable part of the Crater, 28-Oumm Aghouaba fossil lakes.

Average air temperatures are lower (25.2°C) in the Adrar than further south (30.1°C at Moudjeria, 29.0°C at Kiffa). Maximum temperatures occur in June; 34.2°C (up to 41.8°C) at Atar, 38.3°C at Moudjeria, and 34.3°C in May at Kiffa. Average minima in December increase from 19.8°C at Atar to 22.8°C at Kiffa. Throughout the region annual amplitudes (11.5°C at Kiffa - 14.6°C at Atar) exceed average diurnal amplitudes (15.7 - 15.2°C). Annual evaporation averages 3.5 m at Kiffa, 4.5 $m.a^{-1}$ at Moudjeria and 4.2 m at Atar despite the fact that relative humidity may be 10-17% for most of the year in the South but exceed 80% during the monsoon. In the north, even in the monsoon season, relative humidity does not exceed 60%.

2.2.a. GUELTAS OF MOLOMHAR

1. Geography and morphology

The gorge of Oum Lem Har (20°35'N, 13°07'-13°11'W) opens into the sandy valley of Tayaret Cdar, an affluent of the Wadi Seguellil, at an altitude of 245 m. The upper portion of the canyon is situated at 400-450 m. The length of the main gorge is about 6-7 km. A saline pool (Azougui) is situated at its mouth, and pools are found scattered along its course. Their degree of permanence increases as one moves up the valley. A string of elongated upper gueltas above 400 m asl are permanent and with depths exceeding 4 m. During the dry season, the water is mostly stagnant. The upper gueltas receive continuous but minute inputs from numerous small seeps, but this is not sufficient to compensate evaporation. The lower, shallow gueltas are replenished by floods only. Many dry out once or twice a year, and any vertebrate fauna they contain then perishes. Floods occur up to three times a year, with highest probability in August.

2. Water chemistry

Because of the increasing degree of exposure to evaporation downstream, there is a pronounced gradient in salinity along the gorge during the dry season. In February 1976, values for conductivity ranged from $245.10^{-6}S.cm^{-1}$ in the upper gueltas to $3130.10^{-6}S.cm^{-1}$ in the lower gueltas. No measurements were obtained from the saline pools at Azougui, but a saline crust indicates that saturation conditions may be reached at this site. Dekeyser & Villiers (1952) recorded a chlorinity value of 15 $g.l^{-1}$ in March 1951 at Azougui.

The table hereunder presents a set of values for the major ions (in $meq.l^{-1}$) collected from five different gueltas, starting upstream and moving towards Azougui.

	Na	K	Ca	Mg	HCO_3	Cl	SO_4	Cond. ($10^{-6}S.cm^{-1}$)
1.	0.4	0.13	2.7	0.6	3.55	0.6	0.2	245
2.	2.2	0.1	5.1	3.0	4.75	2.7	2.5	635
3.	8.3	0.44	4.4	5.5	4.55	9.9	4.0	1,396
4.	12.0	0.3	10.6	3.8	6.2	13.9	6.6	1,997
5.	80.8	0.36	10.7	8.0	5.1	33.6	5.5	3,130

3. **Macrophytes**

An inventory of terrestrial and aquatic plants is given by Dekeyser & Villiers (1952). Emergent macrophytes are mainly found along the upper gueltas, and are dominated by Phragmites australis, but Cyperaceae and Juncaceae also occur. Among submerged macrophytes, four species of Potamogeton are present. On wet rocky surfaces, the fern Adiantum capillus-veneris abounds. Equisetum ramosissimum and a relict Ficus, Ficus gnaphalocarpa, are also reported.

4. **Phytoplankton**

A short list of algae given by Dekeyser & Villiers (1952) has been much expanded by D'Hollander & Caljon (1978, 1980).

5. **Invertebrates**

Lists of representatives of various groups (Rhizopods, Ciliates, Mollusca, Tardigrades, Crustaceans, various insect orders) were presented by Dekeyser & Villiers (1952). Of particular significance is the presence of the African freshwater medusa Limnocnida tanganyicae Gunther. Interesting relict damselflies are Pseudagrion hamoni Fras., and Molomhar is also a site where the Afrotropical Ischnura senegalensis Ramb. and the Saharian Ischnura saharensis (Ag.), of northern origin, meet. Finally, the West-African snail Bulinus guernei (Dautz.), an important vector of Schistosoma haematobium, is very abundant.

6. **Fish**

Four species occur, all of Afrotropical origin: Barbus deserti (but the Molomhar population might really belong to B. macrops Boul., D. Thys van den Audenaerde, pers.comm.), B. pobeguini Pell., Clarias anquillaris L. and Sarotherodon galilaeus Art.. There are also four species of Amphibia on record: Ptychadena occipitalis (Gunther), Tomopterna cryptotis (Boul.), Bufo regularis Reuss and B. mauretanicus Schl. No true aquatic reptiles occur, but Varanus griseus Daud. abounds around the guelta, and several species of Colubriid snakes have been cited from the wet parts of the gorge.

7. **Human activity**

The canyon is subject to occasional pastoralism and wood gathering. Some hunting by the small settlement at Azougui also takes place. The date palms around the upper gueltas are harvested yearly.

2.2.b. TERJIT

1. Geography and morphology

(20°15'N, 13°06'W) There are apparently two springs at Terjit, situated at the foot of a fault across the narrow gorge that drains towards the Oued el Abiod, resulting in a string of pools and marshes, connected by a trickle of running water over a distance of about one kilometer. According to Dekeyser & Villiers (1952), one spring is cold (water temperature not stated), and one is warm (32°C at origin). In addition to these main springs, numerous seeps occur throughout the gorge. On one of the overhanging walls, a curtain of travertine stalagtites has thus been formed.

2. Water chemistry

The average chemical composition (measured after the mixing of the outflow of the two springs) indicates a Cl value compatible with that given by Dekeyser & Villiers (1952) for both springs individually. The water of Terjit (see table) is notably rich in $CaSO_4$, in contrast to some very nearby gueltas, such as the one of Hamdoun (bed of the Oued Seguellil).

$meq.l^{-1}$	Na	K	Ca	Mg	HCO_3	Cl	SO_4
Terjit	2.80	0.18	18.0	8.8	4.3	3.9	20.0
Hamdoun	0.12	5.4	5.0	2.1	3.5	6.6	1.9

3. Flora

The macrophytes are very similar to those of Molomhar. There are important date palm plantations, and the relict Ficus gnaphalocarpa Rich. also occurs. The Algae were studied by D'Hollander & Caljon (1978, 1980).

4. Fauna

Aquatic invertebrates are numerous, and include the bilharzia-transmitting Bulinus guernei. The fish Barbus deserti (or macrops), and the anurans Ptychadaena occipitalis and Bufo regularis are also present.

5. Human activity

Terjit is permanently inhabited. There is a small maur settlement and some garden-cultures and goat-farming takes place. The date palm is exploited, and plantations were expanding in 1975-76. However, the water supply of the springs is too limited to permit much irrigation. The watering of the gardens and of the newly growing palm trees is therefore effected in the traditional oasis-fashion, by lifting water from man-made wells using a delou, and distributing it through a network of shallow canals across the gardens.

2.2.c. EL BERBERA

1. Geography and morphology

The lakelet of El Berbera is situated (19°59'N, 12°49'W) in a side gorge of the large Oued Timinit. Its canyon is NW-SE oriented and about 3 km long. Its course is lined by date palms and, as it narrows and deepens upstream, surface water appears. At the very top of the gorge, a fairly large lakelet (diameter about 30 m, depth c. 6 m) is found, surrounded by a 5-10 m wide macrophyte fringe, and fed by several springs in the northern wall of the gorge.

2. Water chemistry

A sample collected from the outflow of the lakelet into the lower oasis (April 1975) was analysed. The water is slightly saline, and rich in sodium.

	Na	K	Ca	Mg	HCO_3	Cl	SO_4	Cond. $10^{-6}S.cm^{-1}$
$meq.l^{-1}$	11.7	0.26	8.25	3.10	5.3	11.3	5.8	1,790

3. Macrophytes

No detailed survey has been conducted, but Typha, and several Cyperaceae and Juncaceae occur commonly.

4. Algae

A list of species is given by D'Hollander & Caljon (1978, 1980).

5. Invertebrates

The inventory available is fragmentary. Cladocera and Copepoda were studied by Dumont (1978) and Van de Velde (1984). Only 3 dragonfly species are on record, with Ischnura senegalensis the only damselfly. Among Mollusca, Afrogyrus coretus Blainv., a wide-ranging Afrotropical species, is noteworthy (Van Damme, pers. comm.)

6. Vertebrates

Barbus deserti (or macrops) is found commonly in the flowing water downstream of the main guelta. Possibly, more species occur here, including some Anura, but no collections seem to have been made.

7. Human activity

A small village is established on top of the gorge (to avoid mosquitoes), and the valley is exploited for horticulture and date picking.

2.2.d. GUELTET ZLI

1. Geography and morphology

Gueltet Zli (19°31'N, 12°47'W) differs from previous sites by not being directly connected to a major Wadi system. It is a system of two superimposed gueltas, the upper one small and filled only for short periods after torrential rains, the lower one situated at the foot of an intermittent waterfall, about 40 m in diameter, and 6 m deep when full, completely devoid of macrophytes, and semi-permanent in nature.

2. Water chemistry

At the time an analysis was made (Feb 1976), maximum depth measured was 4 m, and the guelta could be considered more than half full. Its water was fresh, with Ca and HCO_3 the dominant ions.

	Na	K	Ca	Mg	HCO_3	Cl	SO_4	Cond. $10^{-6}S.cm^{-1}$
$meq.l^{-1}$	0.3	0.33	3.56	1.4	2.73	0.6	2.2	352

3. Biota

The impermanence of the lower guelta is reflected in the absence of fish, and hence the presence of large invertebrates that produce drought-resistant eggs (the Anostracan Streptocephalus torvicornis, the large Daphnia similis). Because the guelta dries out at irregular intervals, the molluscan and insect life is also less rich than in permanent waters.

For a list of algae, see D'Hollander & Caljon (1978, 1980).

2.2.e. GUELTA SERIES OF MATMATA (TARTEGA)

1. Geography and morphology

The canyon of Matmata-Tartega (17°53'N, 12°07'W) is about 7 km long, E-W oriented, and progressively narrowing eastward, although its average width is, at all times, in excess of 200 m. The floor of the gorge is covered with numerous gueltas and springs, and marshy areas in which Phragmites and Juncaceae abound. It ends in a cirque-shaped widening, where the main guelta of El Tartega is situated. Its surface area is somewhat variable with water level, but may reach 20-30 ha. It is thus the largest guelta of the Sahara s.l. Its maximum depth is not known. The water of the guelta is turbid, and has a characteristic muddy-brown colour, suggesting it is not very deep. In addition to several yearly floods, the guelta is fed by a considerable underflow. The importance of this source of water to the water balance is stressed by Toupet (1976).

2. Water chemistry

Analyses were made of the water in the main guelta, and of several gueltas and springs in the canyon downstream, in May 1975 and February 1976.

$meq.l^{-1}$	Na	K	Ca	Mg	HCO_3	Cl	SO_4	Cond. $10^{-6}S.cm^{-1}$
main guelta								
1975	9.9	0.2	2.5	2.8	2.0	13.4	0.2	1395
1976	7.9	0.5	6.9	2.3	3.1	16.9	0.3	1785
small gueltas and springs								
1	0.1	0.2	0.9	0.4	0.6	0.3	0.5	127
2	0.3	0.4	1.5	1.7	2.4	0.6	0.6	387
3	0.4	0.4	1.5	1.8	2.5	0.6	0.5	286
4	0.5	0.2	5.4	3.0	3.5	5.6	0.1	265

The relatively high salinity of the main guelta is ascribed to its exposed position. Dominant ions are Na^+ and Cl^-.

3. Macrophytes

Absent from the main guelta; islands of Phragmites and Juncaceae are mainly found in spring areas. No palm trees occur in the Matmata gorge.

4. Phytoplankton

A list of species (with the exception of Diatoms) is given by D'Hollander (1980).

5. Invertebrates

The zooplankton was studied by Dumont (1979). The guelta is the type locality for an eremian calanoid copepod, Metadiaptomus mauretanicus Kiefer & Roy, and a relict site for the Cladoceran Daphnia barbata Weltner. Dragonflies are discussed in Dumont (1978), but no data on other insect groups appear to be on record. Molluscs have not been studied either.

6. Fish

Clarias anguillaris abounds in the guelta, and there are probably Cyprinids and Cichlids as well, but a detailed inventory of species is not available.

7. Other vertebrates

The Amphibia of the gorge are undocumented. Crocodylus niloticus still has a relict population in the main guelta (traces of small to medium sized crocodiles were seen in 1976).

8. Human activity

Except for occasional hunting (crocodiles being one of the targets), and grazing by sheep and goats, no human interference with the canyon occurs.

2.2.f. GUELTA SERIES OF EL HOUSSEINYA, GAMRA OUARBI AND LEMZAILGUE

1. Geography and morphology

(17°44'N, 12°23'W; 17°38'N, 12°23'W). Gamra Ouarbi is composed of a string of gueltas, situated in the hollows of a cascading riverbed. The bottom part is an elongate oxbow-lake. El Housseiniya is a powerful spring that collects into a riverbed that is several kilometers long and stagnant during the dry season. Strong floods occur during the monsoon, which wash the beds of both systems into the main Oued Bourraga. The climate is as for 2.2.e.

2. Water chemistry

The water chemistry (in $meq.l^{-1}$) of the spring outflow, of 4 gueltas in the Gamra Ouarbi series, and of guelta Lemzailgue, is presented below. It is a typical dilute $Ca(HCO_3)_2$ solution.

$meq.l^{-1}$	Na	K	Ca	Mg	HCO_3	Cl	SO_4	Cond. $10^{-6}S.cm^{-1}$
El Housseiniya								
	0.3	0.3	2.4	1.6	2.6	0.4	0.8	157
Gamra Ouarbi								
1.	0.2	0.4	1.8	0.7	2.0	0.06	0.8	239
2.	0.2	0.4	1.0	0.5	1.2	0.06	0.9	157
3.	0.4	0.6	1.0	0.7	1.4	0.06	0.9	161
4.	0.5	0.4	1.3	0.8	0.8	0.3	1.0	215
Lemzailgue								
	0.4	0.4	0.7	0.7	1.3	0.6	0.3	200

3. Macrophytes

While the gueltas are devoid of macrophytes, the bed of El Housseiniya is richly overgrown with emergent and submerged macrophytes, including various Juncaceae, Potamogeton and Nymphaea. The whole valley is covered by an extensive date palm plantation.

4. Algae

With the exception of Diatoms, were studied by D'Hollander (1980), who stressed the species richness of El Housseiniya. The gueltas were dominated by Volvox rousseleti West.

5. **Invertebrates**

A rich assemblage of Cladocera and Copepods (c. 30 species) occurs in the area (Dumont 1979). Among the insects, 9 species of dragonflies were recorded, including Agriocnemis zerafica (Le Roi) and Pseudagrion hamoni Fraser. Bulinus spp. abound in El Housseiniya, but no comprehensive inventory on Mollusca is available.

6. **Fish**

Clarias anquillaris occurs in tremendous population densities in El Housseiniya, and Hemichromis bimaculatus Gill. was also noted here. More fish species are, however, expected to occur here.

7. **Other vertebrates**

Among the Anura, Ptychadena spp. and Bufo spp. occur. A significant record is that of the Nile monitor, Varanus niloticus, in Gamra Ouarbi.

8. **Human activity**

The gueltas are situated in barren terrain, but the oasis of El Housseiniya is exploited for dates. Also, Clarias are caught. Because of the lush vegetation of the Oued Bourraga, there is intense grazing by goats, zebu, and camels. Cattle also use the lower gueltas to water. Some eutrophication (indicated by the abundance of Volvox) results therefrom.

2.2.g. LAKE LE BHEYR (EL BEHER)

1. **Geography and morphology**

The lake is situated (16°33'N, 12°05'W) at an altitude of 75 m. in an almost closed depression at the western edge of the Assaba. It is supplied with rainwater from these mountains, but is probably spring-fed as well (Toupet, 1966). The lake has a limited and temporary outflow to the South-West towards the Oued el Akhdar (Gorgol Noir), an affluent of the Senegal river. It is elongate, and generally N-S oriented. It occupies a shallow basin of maximum 6 km. long. During dry years, and especially in consecutive dry years, it splits up into 2 or 3 separate basins.

2. **Water chemistry**

An analysis was made of a sample collected in May 1975, at the end of the dry season. The water of the lake was still remarkably fresh:

	Na	K	Ca	Mg	HCO_3	Cl	SO_4	Cond. 10^{-6}S. cm^{-1}
meq.l^{-1}	2.7	0.2	2.2	1.2	3.5	2.5	0.3	532

3. Macrophytes

The water of the lake is extremely turbid, and the shores trampled by watering cattle, so that no macrophytes can survive there. The floodplain zone is covered with Piliostigma reticulata. In the upstream guelta of Hairlabe, Toupet (1966) records stands of Typha elephantina. Algae have not yet been studied.

4. Invertebrates

Little is known about aquatic insects. The dragonflies Ischnura senegalensis, Brachythemis leucosticta and Trithemis arteriosa, all wide-ranging African species, were recorded (Dumont 1976). The zooplankton is poor in species and in individuals, an indication of heavy predation pressure by the fish present.

5. Fish

No inventory exists, but Clarias anquillaris certainly occurs, and there is an active Tilapia-fishery (main species: Sarotherodon niloticus and S. galilaeus). No information on other vertebrates is available. The Nile crocodile does not exist in the lake, probably because of human interference. It is still present in quite a few other waters of the Assaba.

6. Human activity

There is a permanent settlement of maurs to the south-east of the lake. Their number increases during the colder dry season, when cattle concentrate on the wetter areas. A Peul village lies a little to the SW of the lake. The lake itself is used for watering livestock, and for fishing. It is strongly eutrophic and turbid, but the upstream gueltas are much less eutrophic. Bilharzia and malaria occur in the area.

2.3. ALGERIAN SAHARA (Fig. 2.4)

2.3.a. OUED SAOURA (Western Algeria)

1. Geography and morphology

The Oued Guir and the Oued Zousfana, drain the southern flanks of the Atlas mountains and meet at Igli to form the Oued Saoura which is a major river extending into the western Sahara. It penetrates between the great western erg, which encroaches on the river's valley in the East, and the erg Chech in the West. Northwards it is bounded to the West by the stony Hammada du Guir. The Saoura has permanent surface water about as far South as the village of El Ouata, S. of the town of Beni Abbes. However, the Saoura used to be noted especially for its strong periodical floods: several pulses per annum were not uncommon. One of these floods due, not to runoff from the Atlas, but to heavy precipitation, mainly on the lower Oued Zousfana on 19-21 March 1959, was described in great detail by Vanney (1960). It was

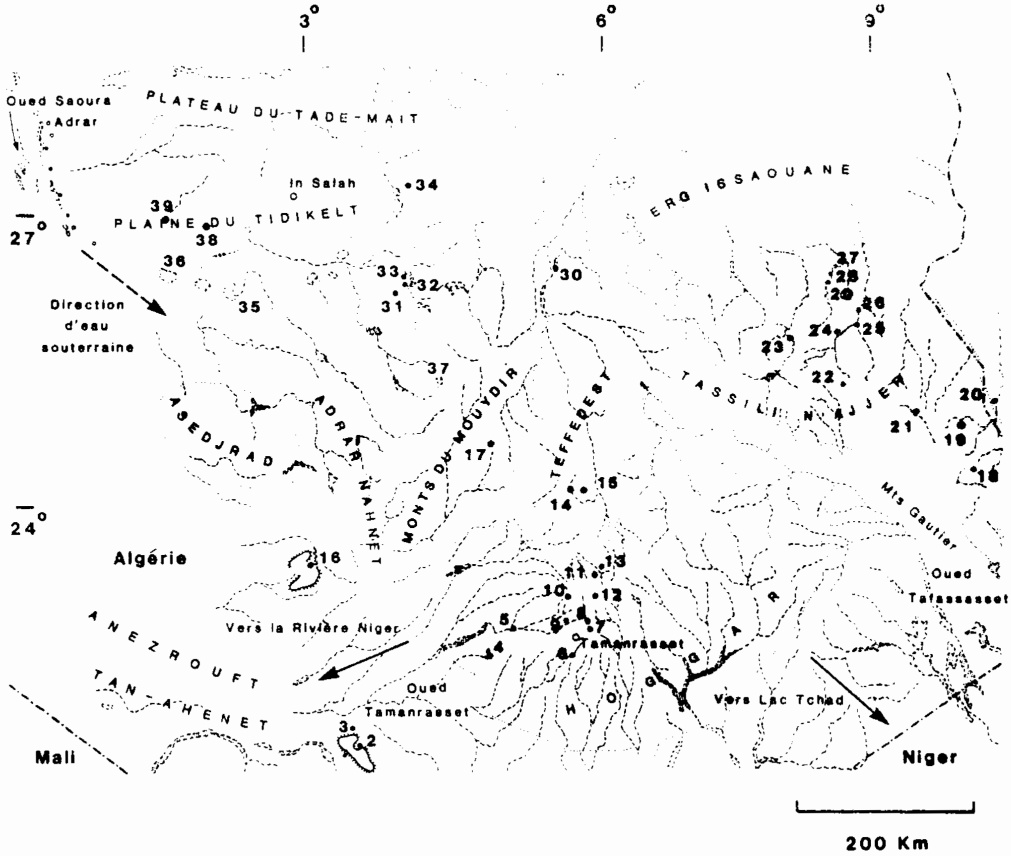

Fig. 2.4 Locations of the permanent and ephemeral surface waters in the Central Saharan mountains (mainly the Ahaggar and northern annexes, and the plateau of Tassili-n-Ajjer). 1-Tedjert Spring, 2-Tamada Guelta, 3-Ti-m-Misaou Well, 4-Silet Spring, 5-Abalesso Spring, 6-Amsel Guelta, 7-Chapuis Spring, 8-Im Laoulaouen Guelta, 9-Otoul Guelta, 10-Terhenanet, 11-Issakarassene Guelta, 12-Afilale Guelta, 13-Tamada Guelta, 14-Hassi Dehine, 15-Mertoutek, 16-In ziza Guelta, 17-Tesnou Well, 18-Amais Guelta, 19-Tamrit Guelta, 20-Ghat Spring, 21-Ga-Bei-Bei, 22-Dider Guelta, 23-Efenni Guelta, 24-Oued Jmirhou, 25-Torset Guelta, 26-Hot Springs of Tihoubar Ti Afella, 27, 28, 29-Oued Djerad Gueltas, 30-Amguid Guelta, 31-Tiguelguemine Guelta, 32-Dijoraf Hot Spring, 33-Essameur Spring, 34-Tamesguidat Hot Spring, 35-Bahar El Hammar, 36-Mekerrhane Sebkha, 37-Arak Springs and Pools, 38-Tit Spring, 39-Aoulef Spring.

felt as far South as Adrar. Periodically even stronger floods occur. Dubief & Cornet (1958) list the frequency with which the Saoura flowed into the desert over specified distances, measured from the source of the Oued Guir for the interval 1900-1957:

flood over	200 km	33 times	
	300 km	13	
	400 km	6	
	500 km	5	
	800 km	1	(March 1959)

An unconfirmed report stated that in 1915 a flood reached Reggane (975 km from source), and this seems to have been a normal phenomenon in the 16th century, when slaves coming from the South were shipped north by boat from Reggane. In the middle of the 19th century, an exceptional flood extended well South of Reggane, as far as the well of Hassi Boura. Because of the damming of the Oued Guir at Djorf Torba, such floods no longer occur. They created enormous, temporary flooded areas of desert land, and strings of pools remained in the southern bed for varying periods of time, some even permanently. The Saoura is one of the main pathways, and certainly the one that was open most recently, in carrying biota of northern origin into the central Sahara.

Two types of stagnant water occur: the flooded valley, and the remaining pools in the river bed. The first is very ephemeral and, although no areas have been studied explicitly, they are probably very similar to the short-term flooded surfaces that occur elsewhere in the Sahara after torrential rains. Pools in the riverbed, on the other hand, show all gradations between ephemeral and permanent characteristics.

2. Climate

Köppen BWa, and West continental Saharian in Dubief's classification. It becomes more and more arid as one moves South through the valley. Desert conditions are reached quite abruptly in the rainshadow of the Atlas; the area of Beni-Abbes has an average of less than 50 $mm.a^{-1}$ of rain, Adrar has only 18 $mm.a^{-1}$, and Reggane c. 10 $mm.a^{-1}$. As in most desert environments, however, there is strong year-to-year variation. In Adrar (258 m asl), for the interval 1912-1968, the absolute minimum was zero precipitation (3 times in 50 years), while the maximum was c. 65 mm. There were five years with more than 50 mm of precipitation. Adrar may also be used as an example for the yearly temperature curve of the lower and middle Saoura valley. Highest mean temperatures are reached in July (c. 34°C), but absolute maxima in July may exceed 50°C. The lowest average falls in January (c. 12°C), but absolute minima may descend as low as -4°C. Winds from S to W dominate in summer; NW to NE winds in winter.

3. Water chemistry

Because of strong seasonal fluctuations in discharge and the ensuing evaporation, the water chemistry varies greatly both in time and space. This has certainly acted as a filter, selectively removing stenoionic (and stenothermic) species from the communities remaining in the valley today. In spring, the upper Oued Guir releases low conductivity water. As the water flows down the valley, and the season advances, evaporation leaves a salt film along the edges of the receding river. The Oued Zousfana is salty over most of its course, most of the year. Whatever water it adds to the Saoura also adds to the salt load of the latter. Also, while the annual floods derived from the upper Oued Guir usually carry relatively little sediment, the few floods that are derived from the Zousfana (e.g. 1959) produce very turbid, reddish-brown water. A further effect of the damming of the Oued Guir is that the valley of the Saoura itself is becoming much more salty. Results of an analysis performed on samples collected in different parts of the valley are presented below.

		Chloride meq.l^{-1}	Conductivity 10^{-6}S. cm^{-1}
Oasis of Tit (Tidikelt)		8.7	1700
Adrar: Foggara		9.3	1250
Saoura, N. Adrar		326.7	more than 10^4
Saoura, Kerzaz	1	14.3	3000
	2	10.8	3000
Saoura, Guerzim	1	10.8	2000
	2	8.2	2000
Saoura, N. Kerzaz		75.9	7400
Saoura, El Ouata	1	111.1	8800
	2	131.7	more than 10^4
Saoura, Beni-Abbes	1	185.9	more than 10^4
	2	400	more than 10^4
Saoura, Igli	1	248.6	more than 10^4
	2	232.1	more than 10^4
Zousfana, Tarhit		22.0	2100
Zousfana, Beni-Ounif	1	41.8	3900
	2	34.1	2300

4. Macrophytes

Because of the variable water level of the Oued, no macrophyte fringe is found in most places. Phragmites occurs locally, and along the seguias of irrigated oases, Typha spp. and various hygrophytes may be found (Phalaris spp., Melilotus spp.). Quézel (1975) studied some communities at Igli from a sociological point of view. He noted the poverty of species and their salt tolerance. He lists Phragmites australis, Scirpus holoschoenus, Sonchus maritimus, Juncus maritimus, Cynodon dactylus as the dominant species. Along the Oued, Tamarix spp and Nerium oleander abound. The dominant tree in the valley is undoubtedly the palm tree. Their number is estimated at more than 500,000.

5. Algae

Stray notes and identifications are to be found in Feldman (1946), Fremy (1930), Gauthier-Lièvre (1931, 1941). Compère (1967) lists 18 species from Adrar. On balance, our knowledge of the algae of the Saoura valley is quite unsatisfactory.

6. Invertebrates

Only pools in depressions remain long enough to allow the development of animal life. It is likely to consist of large Euphyllopods, Notostraca, Conchostraca, Ostracods and large Rhabdocoelids. A community very similar to this is described by Gauthier (1938) from the basin of the Oued Zousfana near Beni-Ounif ("Oued Melias"): the Anostraca Streptocephalus torvicornis, Tanymastix perrieri, Branchipus stagnalis; the Notostracan Triops granarius; the Conchostracan Leptestheria sp.; the Ostracod Cyprinotus incongruens; unidentified Calanoids and Chironomid larvae. Shrimps (Atyaephyra desmaresti) abound along the banks of stagnant sections of the river, and Ostracoda, Cladocera, Copepoda and Rotifera occur plentifully, but no detailed species lists have as yet been published. Among Insects, the same seems to hold true for Coleoptera, Hemiptera and Ephemeroptera. The dominant Zygopteran of the valley is Ischnura saharensis; typical mediterranean species such as Platycnemis subdilatata and Coenagrion caerulescens do not extend beyond Tarhit on the Oued Zousfana. The dominant Anisoptera are Orthetrum chrysostigma, Trithemis kirbyi ardens, and Crocothemis erythraea.

7. Vertebrates

All fish species that live in the Atlas could theoretically occur in the Saoura. Several Barbus species of the callensis-group indeed occur, but many do so only temporarily. When salinity increases, there is back-migration towards the upper reaches (pers. obs. on Oued Zousfana, May 1979). Only very euryhaline species persist, among which the Cyprinodonts Aphanius fasciatus and A. iberus. Among Anura, Rana ridibunda perezi, Discoglossus pictus and Bufo mauretanicus are widespread, especially in date-palm oases.

8. Human activity and management

The valley of the Saoura is densely inhabited, and several major townships (Beni-Abbes, Adrar, Reggane) occur, in addition to numerous villages. Irrigation agriculture and palm culture have probably been performed here since antiquity, and probably there was hunter-gathering activity during the Palaeolithic, and cattle farming during Neolithic times. The Foggara system is still extensively used between Adrar and Reggane and in the Oases of the Tidikelt.

Tourism is developing in the valley, which is accessible by motor-vehicle on a good sealed road. Tourism concentrates on Beni-Abbes (scenery) and on Tarhit (scenery and rock engravings) where modern tourist resorts are available. Problems of pollution exist in the vicinity of the major towns, where sewage is diverted directly into the Oued. This produces off-flavours and local algal blooms (e.g. at Beni-Abbes).

A particular problem has been created by dam-building in the Atlas. The ecology of the river had not been studied in enough detail prior to damming, and the changes that occurred can only be guessed at. Without doubt, however, salinity is on the increase and some selective effect of this on the biota is inevitable in the long run. Large dams, and also some newly constructed fords that fall dry during spring may (and do) hamper the fish in the seasonal migrations mentioned earlier.

2.3.b. GUELTA IN ZIZA

1. Geography and morphology

Guelta In Ziza (23°31'N, 0°12'E) is one of the most isolated surface waters in the Sahara. It is situated at the southern end of the Adrar n'Ahnet and inside a large inselberg of (Cenozoic?) volcanic origin. It has been suggested that this mountain, in fact a circular wall surrounding a wide valley, is the crater rim of a volcano which is partly buried into the surrounding plain of the Tanezrouft. In places, the granitic basement is visible. Rhyolithic glass and alkaline tuffs occur commonly. The guelta forms a circular basin of 13 m diameter and, when full, is about 6 m deep. It collects waterfrom two different oueds that drain part of In Ziza mountain and has no additional spring water input (Monod, 1932). In the bed of the main feeding oued, some additional small basins retain water for some time (hence it is often said that there are several gueltas at In Ziza).

2. Climate

Temperature data are cited by Monod (1932): July is the hottest month (c. 33°C), while in December-January the average is c. 16°C. The climate is likely to be almost identical to that of the southern Saoura Valley, with annual precipitation in the order of $10 mm.a^{-1}$.

3. Water chemistry

A chemical analysis showed that both the guelta and the upper pool with Chara had low conductivity (200 and $600.10^{-6} S.cm^{-1}$ respectively), and chloride content (43 and 128 $mg.l^{-1}$).

4. Biota

In one of the gueltas Characeae were collected in May 1979, but no other macrophytes occur. Algological studies have not yet been conducted. In May 1979, the main guelta was half empty, and clumps of blue-green algae were floating at the surface and lying on the bottom. The zooplankton in May 1979 was rich in the large Calanoid Paradiaptomus greeni. Corixids also appeared to be common. In the bed of Characeae, Chydorids occurred. Dipteran larvae were plentiful in the benthos, but Mollusc. were absent. Two dragonflies were collected: Trithemis arteriosa, a widespread Afrotropical species, and the Mesasiatic Orthetrum ransonneti, which also occurs in the Hoggar and the Air.

The absence of aquatic vertebrates, and the presence of large-sized zooplankton, suggest a periodical drying-out of the guelta.

5. Human activity

The valley of In Ziza supports a single Tuareg family and their cattle (a few camels, some goats). All use the guelta as a multipurpose resource, including for drinking. Eutrophication is apparent.

2.3.c. GUELTAS OF OUED IMIRHOU, INCLUDING ITS AFFLUENTS (OUED IHERIR AND OUED TORSET)

1. Geology and morphology

The Tassili-n-ajjer (Tassili = a tuareg expression for a ring of plateaux which, deeply dissected and locally interrupted, surrounds the central Sahara mountains of the Ahaggar) is named after the Ajjir (or Adjer) tuareg tribes who inhabit that region (c. 3,500 in 1950; c. 10,000 in 1970). It is basically a sandstone plateau of Palaeozoic age that overlies the crystalline (granitic) Precambrian basement. Killian (1922) divided the plateau into three main areas: the northern (and western) upper (or outer) Tassili, which consists of Devonian sandstone, uplifted towards the South (Illizi in the North is 535 m asl.). A series of parallel N-S oriented river beds cut through this plateau and divide it into several blocks: Tanget in the East, Fadnoun in the centre, and Tamelrik in the West. The inner (or lower) Tassili is situated to the South of the outer Tassili. It is composed of Cambrio-Ordovician sandstone and is also tilted in a N-S direction. It is the area where the main oueds, that dissect the Inner Tassili, originate. The Intra-tassili, finally, is a mostly narrow zone between the preceding ones, of Gothlandian age, and best expressed in the V-shaped lower valleys of the main Upper Tassili Oueds, one of which is the Oued Imirhou (or "Mihero"). The dendritic upper reaches of the Oued Imirhou extend southward as a fan, reach 25°10'N, and roughly extend between 8 and 9°20'E. The total basin covers an area of 12,700 km^2. It springs at 1800 m. Certified permanent lakes, as well as a multitude of semi-permanent and ephemeral ones, abound over most of its upper and middle course, including some of its tributaries such as the Oued Iherir and the Oued Torset. The Oued Iherir in the West is particularly famous, and in wet years has flowing water over a distance of 20 km. Here alone, some 45 permanent lakes occur, out of the c. 300 known from the entire Tassili. They are situated at altitudes varying between 1100-1200 m, and some are separated by small but active waterfalls. Their depth may reach as much as 15 m, and many are between 4 and 6 m deep. The Oued Torset also contains numerous permanent gueltas, and near its junction with the Oued Imirhou a hot spring, Tihoubar-ti-n-Afella (c. 45°C) is found, which supplies water to a guelta with the same name.

2. Climate

Little is known about the climate of the plateau area and its deep canyons. While annual precipitation at Djanet is only c. 15 mm.a^{-1}, Bernard (1953) estimates that the plateau should receive 150 mm in good years but the average should not exceed c. 30 mm.a^{-1} (Dubief, 1971). Rains tend to be erratic, with highest probability of occurrence in May. Summer storms that result from hot air masses, cut off from the monsoon front are not unusual. Snow was observed five times between 1925 and 1961. Winter temperature minima in the higher regions are 1-2°C, and maxima do not exceed 13-14°C. Summer minima are 18-21°C, and maxima are around 30°C. Mean irradiation is around 20-25,000 kJ. m^{-1}.d^{-1}, but the microclimates of the permanent lakes are very different, and they receive only a fraction of this energy.

3. Hydrology

In spite of the relatively low precipitation, the upper basin of the Oued Imirhou can collect enough water to produce substantial floods. Some of these have been known to reach a distance of 270 km from the source (Dubief 1971). However, floods of a more modest nature are more common. They even occur without substantive rain, and are driven by a mechanism which is as yet not clearly understood. Floods have been recorded in 39 months over a period of 26 years.

The great variation in longevity of the waters found in the Oued Imirhou (and, indeed, in the whole Tassili), results in wide fluctuations of their ionic content, in time and space. While the Iherir gueltas are incorporated into a flowing river for up to six months per annum, evaporation and concentration of solutes occurs for the rest of the year.

4. Water chemistry

The basic chemistry of six Iherir gueltas sampled in June 1978 is listed below. There was some flow from one to the other, but conditions were basically stagnant. Conductivity and total ionic content varied fourfold.

Oued Imirhou gueltas

	Na	K	Ca	Mg $meq.l^{-1}$	HCO_3	Cl	SO_4	Cond. $10^{-6}S.cm^{-1}$
1	5.1	0.05	2.1	4.2	7.5	3.7	1.0	641
2	7.9	0.1	2.3	2.8	8.5	5.4	1.0	1170
3	6.1	0.1	6.1	7.9	7.8	5.4	1.0	1214
4	6.3	0.1	2.8	8.8	7.1	2.8	6.0	1328
5	7.5	0.3	17.1	10.0	16.4	5.2	12.0	2244
6	5.9	0.2	12.9	19.5	16.5	5.3	12.1	2336

Dry guelta beds in the valley are notably saline; the relatively large quantities of magnesium among cations is striking, while in gueltas 5 and 6, sulphates were very high.

5. Macrophytes

The Oued Imirhou gueltas have thick stands of the Typha elephantina - Typha australis association, sometimes extending over tens of meters as thick green walls, effectively separating adjacent gueltas. Submerged waterplants are also present: Potamogeton spp. are common. Myriophyllum spicatum and Utricularia spp. are locally abundant. Tamarix gallica and Nerium oleander, in addition to thousands of planted date palms, occur in the drier places. The relict olive tree Olea laperrinii is rare: only few specimens are known from Iherir valley.

6. Algae

Little has been published on the aquatic algae of the Tassili-n-Ajjer. Occasional notes are found in Amossé (1941); Behre (1953); Gauthier-Lièvre (1941). Volvox sp. is common in the shallow, eutrophic gueltas; filamentous green algae abound in deeper, semi-permanent gueltas.

7. Invertebrates

The aquatic invertebrates form an intricate mixture of Palaearctic and Afrotropical elements, with the African fraction dominant. Oriental elements also occur but rarely. Unusual species for a desert environment are the poriferan Spongilla carteri and the bryozoan Fredericella sultana. In some gueltas, large Rhabdocoelids abound (Mesostoma sp.). The composition of the zooplankton is determined, aside from historical factors (relicts), by the presence or absence of vertebrate predators and of dense stands of aquatic plants that provide protection against them. It is thus a direct reflection of the degree of permanence of these biotopes. The permanent lakes of Iherir and Torset have only littoral assemblages, or a species-poor zooplankton in which rotifers dominate. The Daphniid Simocephalus vetulus lives among littoral macrophytes (sole site in the Sahara). In turbid waters, the African cyclopoid Thermocyclops retroversus is found. Other significant relicts are Moina belli, an eremian species, and Alona elegans, a Palaearctic species, and among the cyclopoids, Afrocyclops gibsoni, a widespread African endemic (see Lindberg 1953; Brehm 1958; Dumont 1979). In ephemeral gueltas and pools, Anostraca (Streptocephalus, Tanymastix), Conchostrac. (several ill-studied genera and species), and Notostraca (Apus granarius) abound. Diaptomids are also restricted to this type of low-predation environment. Two species of Metadiaptomus, Paradiaptomus greeni and Neolovenula alluaudi, all eremian or Palaearctic in nature, have been recorded (Kiefer 1958; Dumont 1979).

Water beetles also offer a picture of a mixed Mediterranean and Afrotropical fauna (Bernard 1953). The aquatic Hemiptera, studied by Poisson (1953) comprised some 21 species, 13 African and 8 Palaearctic. In fact, some of the species which he classified as Ethiopian belong to groups widespread in Africa, Asia and even Australia, and might be more nearly related to Oriental species. Several dipteran vectors of malaria are present (Senevet et al 1953). Dragonflies (Dumont 1979, 1982) include the eremian Ischnura saharensis and relict populations of Pseudagrion hamoni, an African species. Mollusc. are represented by both Biomphalaria and Bulinus species, and hence both major forms of bilharzia occur in the Tassili. The remainder of the Molluscan fauna also includes a majority of Afrotropical elements, with some Mediterranean species (Van Damme 1984).

8. Vertebrates

Aquatic vertebrates have made the gueltas of the Oued Imirhou famous. The Palaearctic Barbus biscarensis here meets the Afrotropical Barbus deserti; two species of Clarias, a common predator co-occur (C. anquillaris and C. gariepinus). Coptodon zillii has not been recorded at Iherir, but occurs in great schools in Aguelmam Tihoubar-ti-n-Afella and in the Oued Torset. _Bufo viridis_, _Ptychadena occipitalis_ and _P. mascareniensis_ are the dominant anurans. Urodela and water turtles have not been recorded. The most famous inhabitant of the Oued Imirhou was the Nile crocodile. However, it has been extinct here for more than half a century and the exact sites where it used to live ("side canyons of the Oued Iherir") are not known. Three specimens have certainly been killed by Europeans: one in 1909 and two in 1924. The local population was probably small and consisted of dwarfs. One specimen, preserved in Algiers, is 1.40 m long.

9. Human activity and management

The relative abundance of water in the Oued Imirhou and affluents has ensured continuous human habitation, at least since Neolithic times. In spite of malaria (Perret 1933) and bilharzia, the valley of Iherir was inhabited by some 1,000 people around 1950. This number had considerably expanded by the mid 1960s, but then decreased again as a result of the attraction of the oil fields around In Amenas. Agriculture concentrates on dates, wheat, figs, vine, carrots and onions (Bernard 1953), but the Tuareg also know how to exploit the aquatic resources of their valley. Perret (1935) describes a technique, now disused, whereby the women lowered a piece of cloth weighted with stones and baited inside with chunks of goat meat, onto the bottom of the lakes. After a few days, the cloth was quickly hauled up, and the catfish that had been attracted to the meat were caught by hand. The crocodile is not known to have been hunted by the locals, who seem to have feared it, but no memory of their presence remains with today's inhabitants of the valley. As rifles became widely available early in this century, local Tuareg probably contributed to the elimination of crocodiles.

Typha is widely used, for roofing zeribas (huts), a practice which is also known in the Ahaggar and the Tefedest (Mertoutek). The white "heart" of Typha shoots is also used as a vegetable by the Tuareg, and is usually eaten raw.

Human settlements occur not only at Iherir, but also at other sites such as the hot spring of Tihoubar-ti-n-Afella. The valley of Iherir has now been classified as a nature park, and falls under the authority of the Ministry of Fine Arts of Algeria. Emphasis is not on protection of the flora and the fauna but of the numerous frescoes that are found on the plateau west of Iherir. Some basic facilities (huts, guides) are provided for visitors but tourist stress is still neglegible.

2.3.d. GUELTAS OF THE OUED TADJERADJERI

1. Geography and morphology

The Oued Tadjeradjeri, W. of the Oued Imirhou, cuts through the Upper Tassili and separates the plateau of Fadnoun and of Tamelrik. Its lower course, N-NE oriented, extends between 8° and 8°15'E. Numerous gueltas, identical in nature to those of the O. Imirhou, extend along its middle course and upper tributaries, but water is less abundant.

The majority of permanent gueltas extend along the bed of the Oued Aharhar (7°50'-8°E, 25°10'- 25°50'N) an area of historical interest. During the early explorations, the first Flatters expedition reached the junction between the Oueds Aharhar and Tadjeradjeri in April 1880, and turned back N. from there. They found a lake named Mengough (Menrour), situated close to 26°N, about 4 m in depth, and rich in fish. The French Tassili expedition of 1949 led by F.Bernard explored, among other things,the upper Oued Tadjeradjeri and the Oued Aharhar down to Edjef, the site with the last palm trees (25°27'N), but narrowly missed Menrour, which lies in a diverticle about 2 km South of the main oued, and is presently called Aguelmam Efenni (alt. 1120 m a.s.l.). On 5.6.1978, this aguelmam was seen shortly after a flood, and had turbid water. On 17.4.1979, the level was about 1 m lower, and the water transparent to the bottom. The total length of the Aguelmam is c. 500 m; its width varies. In places, it is constricted and even interrupted by dense stands of Typha. Its long axis is roughly N-S oriented; the eastern shore is rocky, while the western side is part of the Oued bed. The French expedition probably overlooked it because, contrary to many other gueltas, it is situated in a fairly open and flat area.

2. Water chemistry

A chemical analysis at the south end, the centre, and the north end of the guelta in 1978 gave the following result:

	Na	K	Ca	Mg $meq.l^{-1}$	HCO_3	Cl	SO_4	Cond. $10^{-6}S.cm^{-1}$
1	1.8	0.2	8.4	3.4	5.9	2.4	5.0	741
2	1.6	0.1	5.4	4.1	5.9	2.2	3.2	527
3	4.3	0.4	5.7	4.3	5.9	3.4	4.9	779

These are typical freshwater conditions. However, in 1979 a white salt film occurred on the dry parts of the guelta bed, indicating that salinity may fluctuate quite strongly.

3. Flora

Typha is the dominant macrophyte. Potamogeton occurs locally, and so do some Characeae. Micro-algae have not been studied. There are no palm trees in the immediate vicinity which may account for its being inconspicuous. Instead, Tamarix occurs in the Oued bed, and Acacia on the surrounding stony plateaux.

4. Fauna

Four fish species co-occur with certainty in the guelta; the predator Clarias gariepinus (det. J. Teugels), Barbus biscarensis, B. deserti and Coptodon zilli. The open water zooplankton is impoverished, while in the Typha stands various cyclopoids and Cladocera (Chydorids, Macrothrix spp., Ceriodaphnia spp.) are found. The benthos contains Ostracods (Martens 1981), chironomids, Ephemeropteran and Odonata larvae. Aquatic beetles and waterbugs are numerous. Two dragonfly species, not yet found elsewhere in the Tassili were recorded: Trithemis annulata and Paragomphus genei.

Other sites visited by the French team are temporary pools in the upper Tadjeradjeri at Armar, 1100 m. Their fauna remains undocumented, but is probably similar to the calanoid and anostracan plankton found in a series of kettle holes ('marmites de géant') named Aguelmam Tin Azzaret in the Oued Adji, an affluent of the Oued Samene, the first Oued West of O. Tadjeradjeri and only 25 km West of Ain Tairhe (25°52'N, 7°44'E). In the upper Aharhar, Ag. Adjeraoua (1160 m) occupies a typical guelta-site. It is said to be permanent, and rich in insect life, with the gyrinids Dineutes grandis and Gyrinus regimbarti explicitely recorded (Bernard 1953).

5. **Human activity**

A well, Ain Tairhe (1120 m), situated some 3 km N. of A. Efenni, was visited by the French Tassili expedition. It is here called Foggara of Aharhar, and the spring is named Tamera. It was captured, and surrounded by a concrete basin in 1947. Canals were dug to conduct its water to the village of Aharhar. Gambusia was introduced into the canals to control mosquito larvae.

There is a settlement at Aharhar, including a date palm plantation (palmeraie), at 3 km from the guelta of Efenni. Its influence on the guelta is limited. No fishing occurs. There were 400 inhabitants here in 1950, but only few families in 1978-79. Most of the workforce had moved to In Amenas. Grazing and watering by goats and camels is the only use that is made of the gueltas in the area.

2.3.e. AGUELMAM TIN BAWENDI (TAMADJERT)

1. **Geography and morphology**

The village of Tamadjert (25°37'N, 7°19'E) is situated W. of a large fossil floodplain, c. 8-10 km across, at c. 1160 m. asl. and at the confluence of two major and one minor gorges. The central gorge, Oued Tin Bawendi, is still extremely humid, and contains a series of gueltas over a distance of several kilometres, separated by long, dense stretches of Typha, sometimes united by a narrow channel of stagnant or running water. There are springs in several places. This system, entirely situated on the inner Tassili, is not connected directly to any of the major Oueds of the Tassili.

2. **Flora**

Potamogeton, Ceratophyllum, Myriophyllum, Polygonum and Characeae abound.

3. **Fauna**

A single, preliminary inventory was made on 18.4.1979. No Mollusca were seen. The largest guelta, several meters in depth, contained Calanoids, Cyclopoids, larvae of Ephemeroptera and of Chaoborus. In the submerged vegetation, species-rich communities of Chydorids (Alona, Pleuroxus), Macrothricids, and Ceriodaphnia were found. The macrofauna consisted of Coleoptera, Hemiptera, Diptera and Oligochaeta. No fish were seen (as confirmed by the presence of Calanoids in the open water) but Bufo viridis and Rana ridibunda perezi were numerous, as were Colubriid snakes that fed on them.

4. **Human activity**

The drier parts of the gorge provide excellent grazing, and cows and goats freely roam about through the canyon. The small villages of Tamadjert and Edjef Eberchenaten also conduct limited horticulture. Of special interest is the fact that the area is rich in neolithic frescoes, indicating continuous habitation of the area since prehistoric times.

2.3.f. AGUELMAM AZAR (ASSAR) AT DIDER

1. Geography and morphology

The gueltas of Azar (or Assar, Assa) (25°12'N, 8°28'E) are named after the Assar massif which (mean altitude c. 1600m) rises some 150 m above and south of the vast plain of Dider. They are situated in the bed of a short (2-3 km) gorge that drains the N. of this plateau and consist of a number of upper pools, and two large lower pools, separated by a cascade. All pools are rain-fed and none is permanent. The upper ones are small, elongate, shallow and lie in cracks in the bed of the oued. The basal ones are circular plunge pools, several meters deep; the lower one is c. 30 m diameter, and 4-5 m deep when full.

2. Biota

No macrophytes or vertebrates live here, and all these gueltas are excellent examples of environments fully exploited by large invertebrates. The small upper pools are rich in Triops granarius, large Ostracods, Daphnia, conspicuously red-pigmented calanoids, large rhabdocoelid flatworms, and no mollusca. Large flocs of filamentous green algae are abundant. The lower gueltas are populated by dense swarms of Anostraca, red calanoids, and, in the benthos and epilithon, Trichoptera larvae, Ostracods, Oligochaetes and mites.

3. Human activity

The upper gueltas appear to be of no interest to the nomads living around the plain of Dider. The lower guelta (Azar s.s.), however, is frequently visited by Tuareg, to wash, drink and water cattle. Small caravans come almost daily to the guelta and drinking water is taken away in guerbas carried by mules. The gorge is lined by a number of overhanging cliffs, most of which contain rock paintings.

2.3.g. GUELTAS OF IMLAOULAOUENE

1. The Hoggar: Geology and morphology

The Ahaggar or Hoggar mountains are basically made up of Precambrian granitic rock, but the highest parts are covered by late Tertiary and Quaternary lavas, deposited in three distinct phases of volcanism that were related to the Alpine orogenetic revolution. It covers an area of 3.10 km^2 around a central core, the Atakor (or Khoudia, in arabic) at about 1900-2200 m asl. The fantastic relief of that part of the Hoggar today, with its many sugerloaf-shaped peaks, is the result of differential erosion which removed the volcanic cones but left most of the magmatic cores intact. The Hoggar mountains are drained by a number of rivers, the most important of which is the Wadi Tamanrasset to the west of the massif. It is itself a tributary to the Oued Tilemsi, a fossil river that used to empty into the Atlantic Ocean in West Africa but was captured in its lower reaches by the River Niger, possibly around 6,000 B.P. The gueltas of Imlaoulaouene (22°53'N, 05°40'E) are situated in a short side gorge of the Oued Tamanrasset, close to the city of the same name. A fault across the river bed causes the underflow to seep to the surface near its top and this forms a cascade with four main steps (= guelta basins). The lower guelta is at 1500 m, the upper one at 1540 m.

2. Climate

Although situated in the centre of the Sahara, the climate of the Hoggar is distinct from, and much less extreme than, that of its surroundings. Precipitation is much higher, and increases steeply with altitude; the city of Tamanrasset (1400 m) has c. 50 $mm.a^{-1}$, while the Assekrem peak (2700 m) has no less than 125 $mm.a^{-1}$. Mean annual temperature at Tamanrasset is 21°C; the minimum falls in January (11.7°C) and the maximum in July (28.9°C). Freezing temperatures occur every winter, with an average of 29 frost days (20 in January, 9 in February); -6°C is the absolute minimum. At higher altitudes (Assekrem), snow is not exceptional (once in four years), and the absolute minimum is about -12°C. Consequently gueltas freeze regularly in winter.

Irradiance c. 20,000 $kJ.m^{-2}.a^{-1}$. varies with the season and the relative importance of short wavelengths increases sharply with altitude. On the Assekrem plateau values close to the solar constant are frequently measured, especially when partial cloud cover adds reflected to the direct incident light (Schwarz 1976). As in most desert environments, inter-annual variation is strong. Between 1924 and 1968 (Tamanrasset altitude) annual precipitation was around 10 mm in 7 years but there were more than 100 mm in 5 years. In 1933, a historical maximum of almost 160 mm was recorded. At the Assekrem, between 1955 and 1968, only three years had less than 100 mm (absolute minimum c. 35 mm), while there were three years with more than 200 mm (absolute maximum in 1957: 260 mm). Even in the former conditions all local oueds flow for at least a few days each year. This is greatly facilitated by the impermeability of the granitic substratum. The Oued Tamanrasset, for example, flows for an average of 5 days per annum and 5-6 times during the present century it flooded sufficiently to reach the Tanezrouft, possibly as far as the Tilemsi. It is certain that the area of Tim-m-Missao on the central Tanezrouft was reached in September 1950 and 1951 (Teissier, 1965).

In its central position, the Hoggar derives its precipitation from two sources, and has two annual maxima: a winter-spring one, related to Mediterranean depressions, and a summer one, related to advances of the monsoon front. This bimodality is more marked at Tamanrasset than on the Assekrem, where only the winter months have a relatively lower precipitation.

3. Water chemistry

Like all intermittantly replenished desert waters, the ionic content of the gueltas varies strongly with time after filling. The water seeping in at the top of the fault is insufficient to compensate for evaporation (actual measurements of evaporation by Schwarz (1976) extrapolated to the altitude of the gueltas would indicate an annual total of around 4 m), so the main water supply must be from torrential rains. In September 1976, shortly after some good rains, the lower guelta was full (and turbid), and had a conductivity of $153.10^{-6}S.cm^{-1}$. In February 1977, the water level had declined by about 1 meter, but the water was now clear. The conductivity of the lower guelta had increased to $238.10^{-6}S.cm$, while the basin above it had now $482.10^{-6}S.cm^{-1}$. In May 1980, the level was about the same as in February 1978 and so was the conductivity of the lower guelta ($450.10^{-6}S.cm^{-1}$). Conductivity of c. $1500.10^{-6}S.cm^{-1}$ was measured in some small puddles of water which still persisted at the upper levels. They were surrounded by a salt film and salt deposits were also seen on the base of _Typha_ stems there. This situation is reminescent of the Molomhar series of Mauretania, but in inverse order. Here conductivity decreases downstream, because the gorge deepens abruptly, and the lower gueltas are very well protected from evaporation, while the upper ones are not.

4. Flora

Above and below the fault, _Nerium oleander_ occurs in the bed of the Oued. The lower gueltas are completely devoid of macrophytes, but at the seep itself, _Typha_ stands occur, and Characeae and mosses are also found. D'Hollander (unpublished) identified a few algae from the guelta: _Oscillatoria tenuis_, _Volvox rousselettii_, _Korshikoviella gracilipes_ and _Ulothrix_ sp.

5. Vertebrates: None recorded.

6. Invertebrates

Some Hemiptera and Coleoptera occur in the lower gueltas, but are much more numerous in the vegetated higher pools. They are the same species as found in the gueltas of the Assekrem plateau (see below). Dipteran larvae and Ephemeroptera also occur, and mites are relatively common. The dragonflies _Pantala flavescens_, _Trithemis arteriosa_, _Orthetrum chrysostigma_ and _O. ransonneti_ patrol over the gueltas and in the dry bed of the Oued. The zooplankton consists of the cyclopoids _Tropocyclops prasinus_ and _Metacyclops minutus_ but predominantly the calanoid Neolovenula alluaudi, the Cladocera Daphnia simili, Moina micrura, M. belli and Ceriodaphnia dubia, and the anostracan Streptocephalus torvicornis. The Cladocera, and particularly the calanoid copepod, are conspicuously pigmented.

7. Human activity and management

Goats and camels frequently come to the gueltas to drink. They are, however, not used by humans for that purpose any longer. The lower guelta, being situated at less than 20 km from the city of Tamanrasset, and close to the motorable track of the Assekrem circuit, is visited by numerous tourists. Apart from the local accumulation of some litter in the environment, no detrimental effects of this activity are apparent.

2.3.h. THE GUELTAS OF THE ATAKOR

1. Geography and morphology

This section covers a selection of the numerous (c. 40), mostly permanent waterbodies that are situated in the heart of the Atakor, on or around the high (1800-2200 m) plateau of Assekrem. Rivers have eroded the lava sheet that covers the area, and cut gorges down to the crystalline base. Permanent seeps and springs are found at the boundary between lava and granite, and several semi-permanent to permanent stretches of running water result. Data are available about the gueltas of Affilal (2100 m, 23°11'N, 05°42'E), Issakkarassene (1950 m, 23°25'N, 05°47'E), the twin gueltas of Imeghra (Imarera) (1840 m, 23°27'N, 05°50'E) and the gueltas at the palm trees of Edjif Mellene (Tamada) (1800 m , 23°27'N, 05°51'E). Most are situated in fairly open riverbeds; only the Imeghra gueltas are in a plunge-pool site, while the lower gueltas of Affilal have eroded a number of kettle-holes (marmites de géant) into the Precambrian granite. The top guelta of Affilal, an elongate, weedy pool, is permanent, but the marmites are partially intermittant. All the other gueltas consist of strings of pools in deepened sections of their riverbeds, connected by some running waters for most of the year. Because precipitation at this altitude is fairly evenly spread over the year, the changes in water level are not rhythmical, and floods may wash out accumulated salts from these systems at any time.

2. Water chemistry

A series of analyses was performed on samples collected in February and March 1977. A wide variety of sites was sampled, including almost dry puddles, and the open water of the largest gueltas (see table).

$meq.l^{-1}$	Na	K	Ca	Mg	HCO_3	Cl	SO_4	Cond. $10^{-6}S.cm^{-1}$
Affilal:								
Guelta	0.8	0.3	1.4	1.1	1.8	0.5	1.0	243
kettle hole	2.2	0.3	1.9	2.8	5.1	1.0	1.1	484
Issakkarassene:								
guelta (mean of 3 sites)	1.0	0.6	2.9	2.3	4.3	0.8	1.1	550
spring	1.0	0.6	1.6	1.6	2.2	0.4	1.6	350
pool	1.2	0.4	6.2	3.9	7.1	1.8	1.5	1100
Edjif Mellene (Tamada):								
least mineralised site	0.6	0.1	0.6	0.1	0.5	0.7	0.2	160
most mineralised site	3.6	0.4	1.4	5.3	6.3	4.1	1.2	915
average of 8 sites	1.7	0.4	2.7	1.1	3.7	1.8	0.9	560
Imeghra (Imarera):								
pool	9.8	0.6	1.8	7.0	5.4	3.7	10.6	1260
guelta	0.8	0.3	1.4	1.5	2.4	1.1	1.0	200

The variation in concentration is roughly one order of magnitude; because of the very weakly mineralised nature of the spring water, even the most concentrated waters analysed are still in the oligohaline range, and not selective for most biota. Altitudinal effects are probably much more important in this respect.

3. Macrophytes

The association of Typha australis and Typha elephantina occurs up to 1600 m; all Atakor gueltas have only T. australis, often in great density. Phragmites australis may also form dense stands, often in places that are only temporarily flooded. Stems up to 4 m in height occur around the twin gueltas of Imeghra. Scirpus holoschoenus, Polypogon monspeliensis, Juncus buffonius often co-occur with it. The drier parts of the oued beds are characterised by Tamarix gallica, Nerium oleander and sometimes fig-trees. Palm trees are rare at this altitude. A small stand occurs at Edjif Mellene (edjif = arabic for palm tree) only. Submerged waterplants include three species of Potamogeton which are fairly common: P. panormitanus, P. perfoliatus and P. hoggariensis. The relict olive tree, Olea laperrinii, lives in erosion gullies that lead to the gorges.

4. Algae

D'Hollander (unpublished) identified a number of algal species from the gueltas. Although her inventory is far from complete, it is the only modern one available, and the only source of information since Gauthier-Lievre (1941). She lists the following 25 taxa: Microcystis incerta, Nostoc sp.; Oscillatoria limosa, Spirulina major, Trachelomonas hispida, T. intermedia, T. volvocina, Peridinium inconspicuum, Volvox rousselettii, Dictyosphaerium pulchellum, Scenedesmus acuminatus, S. ecornis, Ulothrix sp., Aphanochaete repens, Oedogonium sp, Cladophora glomerata, Closterium leibleinii, C. moniliferum, Cosmarium laeve, C. subprotumidum var. gregorii, C. turpinii, C. turpinii var. hoggaricum, Mougeotia sp., Spirogyra sp., Zygnema sp.

5. Invertebrates

The gueltas are rich in benthic and littoral Ephemeroptera, Trichoptera, water mites and Oligchaetes, few of which have been studied taxonomically. More information exists on the Coleoptera (e.g. De Peyerimhoff, 1938). Species widely found in the Atakor gueltas are Bidessus minutissimus, Hydroporus optatus, H. pubescens, Agabus bipustulatus, Meladema coriacea, Dytiscus circumflexus, Gyrinus substriatus and Ochthebius quadrifossulatus. Some 10 species of Hemiptera (Poisson 1929 a,b) have been reported. Four species are Palaearctic (mainly Notonecta and Corixa), 5 Afrotropical (mainly Anisops), while Anisops sardea is wide-ranging on at least three continents (Hutchinson 1934). The dragonflies are a mixture of eremian species of northern or middle-eastern origin (3 species), with some African relicts (e.g. Trithemis kirbyi ardens), but no Pseudagrion, a reflection of the altitudinal limitations on the fauna. The zooplankton is fairly rich in species, but since most of the gueltas have planktivorous fish, there are few open-water species. In small pools, and in the kettle-holes of Affilal, where no vertebrates are present, the same planktonic assemblage as in Guelta Imlaoulaouene is found. A significant relict species of the Hoggar is the cyclopoid Cyclops abyssorum divergens, which belongs to a genus typical of temperate and northern Eurasia. The closest population of this taxon is found in the Tell-Atlas, Tunisia (Dumont, 1979). Among chydorid Cladocera, the genus Chydorus is completely absent, and replaced by Pleuroxus aduncus and Oxyurella tenuicaudis, both of northern origin, which abound here.

6. Vertebrates

The altitude excludes aquatic reptiles. Rana ridibunda perezi and Bufo viridis represent the Anura. Barbus biscarensis is extremely abundant, and B. deserti has also been claimed to occur. Other species, found in the Tassili-n-Ajjer and even in the Mouydir (e.g. Coptodon zilli) do not tolerate the cold winter temperatures of the high gueltas.

7. Human activity and management

The Atakor area is sparsely inhabited, and the gueltas do not attract human settlements. Quite a few are situated close to the tourist circuit of the Assekrem (which requires a four-wheel drive vehicle), and side roads from the main track lead straight to the gueltas in at least two places. Many tourists therefore visit the gueltas, as a desert feature, but this seems to have little effect, apart from some casual swimming and picknicking, and the danger of human interference with the guelta ecosystem appears remote.

2.3.i. THE GORGE OF ARAK

1. Geography and morphology

The Emmidir or Mouydir mountains, where Arak is situated (25°17'N, 03°41'E) geologically belong to the Hoggar core. They are composed of Precambrian, granitic rock. The climate is more nearly related to that of In Salah than to that of Tamanrasset, a reflection of the lower altitude (560 m) of the main part of the gorge. Its aquatic environment is composed of a number of periodic and permanent gueltas situated in a narrow upper c. 700 m a.s.l. canyon, not easily accessible and a widening gorge at lower altitude (560 m), where the groundwater touches the surface in several places to form shallow, productive pools.

2. Water chemistry

An analysis made on a sample collected in September 1976 in the lower gorge at high water level revealed fresh water, with a total ionic content of c. 13 meq.l^{-1}. Doubtlessly the salinity may rise by an order of magnitude, during dry spells.

Arak lower gorge

meq.l^{-1}	Na	K	Ca	Mg	HCO_3	Cl	SO_4
	2.3	0.26	2.2	1.5	2.6	2.5	1.3

3. Macrophytes

Quézel (1965) regards the association of macrophytes found at Arak as typical for the Sahara; it consists of extensive stands of Typha australis and Typha elephantina with abundant Phragmites australis. Submerged macrophytes include the Potamogeton species found in the Hoggar, Rupia spiralis, and Myriophyllum spicatum. Tamarix gallica and Nerium oleander abound everywhere in the drier parts of the oued bed.

4. Algae

Compère (1967) lists 10 species from an unspecified waterpoint, almost certainly in the lower gorge. Diatoms were the dominant group.

5. Invertebrates

There is a rich insect life in the gorge, very reminiscent of the Tassili-n-Ajjer (Coleoptera, Hemiptera, Odonata). The Middle-Eastern and Mediterranean dragonfly Selysiothemis nigra reaches its southern limit of distribution here. The zooplankton in the lower pools, richly overgrown with macrophytes, is a diverse assemblage of cyclopoids and chydorid cladocera. The water plants also provide shelter for numerous Dipteran and Ephemeropteran larvae, Hydracari, Rotifera, and for Oligochaeta, all of which deserve further study.

6. **Vertebrates**

There are no fish in the lower gueltas, but Coptodon zillii lives in the higher, permanent gueltas. Rana ridibunda perezi, Bufo mauretanicus and Bufo viridis also occur here.

7. **Human activity and management**

A bordj (fort), at one time used as a hotel, is found in the lower gorge, close to the weedy pools. It has long attracted tourists to the grandeur and scenery of Arak canyon, but is at present disused. There are, however, still a few fairly sizable Tuareg villages in the gorge. The trans-Sahara highway crosses the gorge. Since it was sealed in 1977, the number of visitors to the gorge has increased by an order of magnitude.

2.4. CHOTT EL DJERID, CHOTT EL FEDJEDJ AND CHOTT EL GHARSA (S. TUNISIA)

1. **Geology and geomorphology**

Chott el Djerid (c. 33°5'N, 8°E, 4,600 km^2), Chott el Fedjedj (c. 33°75'N, 9°E, 800 km^2), and Chott el Gharsa (c. 34°25'N, 7°75'E, 600 km^2) combine to form the largest closed depression among the lagunar environments of North Africa. It is the easternmost of a chain of depressions that extends deep into Algeria. Chott el Djerid occupies the cuvette of an asymmetrical synclinal. Further East, Chott el Fedjedj reaches as close as 22 km to the Mediterranean shore, just North of Gabes. It lies in the axis of an eroded anticlinal of Palaeocene age. The basin of both Chotts combined is 10,500 km^2. Their bed lies at a minimum altitude of 15 m a.s.l. Geologically, their northern half rests on Cretaceous rocks, which outcrop to the North and East as low mountain chains (e.g. the Cherb mountains and Jebel Tabaga, of middle Cretaceous age). Their southern part belongs to the Precambrian Saharian shield. The central depressions were subsequently filled by Tertiary and Quaternary alluvial clay and gypsum. The morphology of this area has remained stable since the late Pliocene, when the synclinal of el Fedjedj was eroded to its present level. The Pleistocene is noted for the second orogenic phase of the Atlas (the first one being of early Tertiary, post-Lutetian age). During the Villafranchian, the chain of Cherb was pushed up. A lagoon was established South of it until that time, which communicated with the gulf of Gabes in the East, and extended West as far as Chott Melhrir (Algeria). It became delimitated to the North by this crustal movement. However, the communication of the Chotts with the sea (and between the Chotts themselves) was interrupted only in post-Tyrrhenian times (c. 200,000 B.P.). These correspond to the onset of a progressive drying up and salinification of the now closed basins. Coque (1962) finds evidence for alternations of humid-cold and warm-dry spells during the Quaternary in Chott el Djerid. These stimulated mechanical erosion, and added to the rate of sedimentation, previously determined mainly by evaporation.

2. Climate

The average precipitation on the basin of Chott el Djerid is 134 mm.a , $^{-1}$or a total volume of 1.4 10 m^3 a ^{3}: $^{-1}$The maximum occurs during winter (October-March), and rains are often torrential. There is a steep gradient in precipitation between the coast (Gabes: 185 $mm.a^{-1}$) and inland (Kebili: 95.6 $mm.a^{-1}$) such that the isohyet of 100 mm, defining the onset of true desert conditions, passes right through Chott el Djerid. Air temperatures identify a hot season (March-September) and a winter season (October-February). Maxima are reached in July, with mean maximum of 42°C and a mean minimum of 22°C at Tozeur. In Gabes, the maximum is reached in August and is only 32.3°C, and the minimum 22.4°C, an illustration of the cooling influence of the sea. The winter minima, likewise, are 3.7-15.7°C at Kebili, and 6.2-16.2°C at Gabes, in January. Yearly evaporation is 2.4 m (Metlaoui), and average irradiation is c. 18,000 kJ $m^{-2}.d^{-1}$.

3. Groundwater geology

The Chott el Djerid basin has three superimposed artesian groundwater tables, separated by layers of impermeable clay. The "continental intercalaire", a term coined by Killian (1922) to indicate the strata between the end of the carboniferous and the middle Cretaceous (Cenomanian), is mainly charging Chott el Fedjedj, and to a lesser degree Chott el Djerid. The "continental terminal", a sequence of clays and gypsum deposited between the Lutetian (middle Eocene) and the Pliocene, charges Chott el Djerid by infiltration of precipitation on the Atlas and Dahar ranges. Outflows from this groundwater table occur on the North and South edges of the Chott, where there are numerous springs with discharges of 3.5-5 $m.s^{-1}$. Many of them are thermal and their salinity increases from S to N ranging approximately from 1-3 $g.l^{-1}$. The superficial groundwater (and the surface water) is situated within and on top of Pleistocene clays, sands and gypsum. It is derived from direct precipitation on the Chotts, and to a minor degree from run-off in the basin. Its salinity decreases from the top, where values up to 300 $g.l^{-1}$ are found, to c. 100 $g.l^{-1}$ in the underlying sandy layers.

4. Water balance

The combined yearly input into Chott el Djerid and el Fedjedj is $1.22x10^9m^3$; $0.48x10^9m^3$ derived from recharging the groundwater, and $0.74x10^9m^3$ from direct precipitation. Runoff represents only 2% of the latter. Evaporation losses (estimated at over 2500 $mm.a^{-1}$) are, however, well in excess of this, and a negative figure of $6.9x10^9m^3$ (for a surface of 5400 km^2) was calculated for one year by Gueddari (1980). He also estimates that, since the Chotts became established in their present form, some 200,000 y ago, $216x10^9$ t of salts have accumulated here, either in suspension or as evaporites. This includes, $89.5x10^9$ t of halite, and $95.4x10^9$ t of gypsum. The post-Tyrrhenian evaporites alone are composed of $18.2x10^9$ t of halite, $151.1x10^9$ t of gypsum, and $0.6x10^9$ t of KCl. The ratio of these salts suggests a continental origin which supports the view that Chott el Djerid functioned as a shallow deposition basin since the end of the Villafranchian, and became evaporative and lacustrine with the closing of the lagoon after the Tyrrhenian.

5. Water chemistry of some surrounding waters

It is pointless to present analyses of the waters of the Chotts themselves; after strong rains in spring, when the basins fill up, dilution occurs, and their waters are turbid and muddy. Sedimentation is rapid and they evolve into saturated brines, that eventually dry up and leave only a salt crust of variable thickness. Surrounding waters are of two kinds: more or less permanent oueds draining towards the Chotts, and permanent springs. All of them are strongly mineralised. Some examples are given in the table.

$meq.l^{-1}$	Na	K	Ca	Mg	HCO_3	Cl	SO_4	Cond $10^{-6}S.cm^{-1}$
Oueds draining towards Chott el Fedjedj:								
Oued el Hamma	5.2	1.4	20.3	9.1	4.5	25.1	6.8	2931
Oued 80 km E. Kebili	13.3	1.0	16.7	10.5	5.0	35.3	7.0	3481
Effluents of springs:								
- draining towards Chott el Gharsa								
Chebika	3.9	1.1	12.2	16.6	4.4	20.2	10.2	2565
Gafsa (Oued el Melah)	3.4	0.1	15.2	8.9	4.3	12.9	8.6	1375
	4.0	0.2	15.3	6.6	4.5	12.8	9.0	1780
- draining towards Chott el Djerid								
Douz	4.3	1.0	12.0	8.0	4.5	20.3	4.5	2315
Djemmaa	2.8	0.9	6.1	4.5	3.3	9.0	2.5	1335
Kebili	6.4	0.7	20.9	21.3	3.4	40.6	9.5	4908
- draining towards Chott el Fedjedj								
El Hamma: Ain el Bordj	4.8	1.1	23.0	4.7	6.0	20.3	6.2	2690

6. Biota of the Chotts

The Chotts are poor in plant and animal life. Of the species one might expect in such an environment, Dunaliella has not been cited and even Artemia sp. does not appear to be common. Occasionally, brine pools develop a deep purple colour, indicative of purple bacteria. The ciliate Fabrea salina, sometimes peaks in great numbers. Aggregates of Phormidium corium (cyanobacteria) were found under salt crusts by Serpette (1947). The saline spring El Mensof (20 m), inside the Chott, is richer in cyanobacteria: Aphanothece microscopa, Spirulina meneghiniana, S. subsahara occur here. Two water beetles, Ochthebius salinator and Paracymus maximus also occur. Similarly, a spring exists inside Chott el Fedjedj (Ain Trarfi, 25 m). With less than 6 $g.l^{-1}$ of total dissolved salts, it is comparable to the springs that abound around the Chotts, and it has a similar fauna. The Cladoceran Daphnia magna occurs here, beside several species of Hydrobiid snails (Seurat 1938).

7. Biota of the Oueds, Seguias and springs

A most diverse fauna and flora is found in the string of springs and oases that surround the Chott area, in the Region of El Hamma (de Gabes), Kebili, Tozeur-Nefta and in the so-called "mountain" oases north of Chott el Gharsa, in the Djebel en Negueb. Thermal springs abound around El Hamma, with water temperatures as high as 51°C. Those at El Hamma itself are quite famous and three among them contain the Pancarid crustacean Thermosbaena mirabilis. Their outflow is characterised by massive developments of filamentous cyanobacteria and associated diatoms (Monod 1940; Dumont 1978), that may extend for some distance into the seguias of the surrounding oases. As the water cools, filamentous green algae, Characeae and, in the more mineralised springs, Enteromorpha develop. Ruppia spp., Zannichellia palustris and Scirpus littoralis are found in the wider sections of nearly stagnant water, and Typha-meadows form locally where swampy sections occur. Among the strands of periphytic algae and macrophytes, a microfauna develops, reduced to nematodes and amoebae in the hot springs. In cooler water, numerous gammarid amphipods, cyclopoid and harpacticoid copepods, and chydorid Cladocera appear, together with snails (Hydrobiids, Melanoides tuberculata, several species of Bulinus), a Pisidium-species and shrimps (Palaemonetes spp.). On damp shores, terrestrial amphipods (Orchestia spp.) and Isopods, the most interesting among which is Saharolana seurati (spring of Ras el Ma near Kebili), abound. Wells in the area have yielded phreatic Asselids: P. coxalis africanus and P. bragadicus. The dominant groundwater animal, however is Gammarus rhipidiophorus. Insects are represented by numerous dragonfly species (Dumont 1977), Hemiptera, and Coleoptera. The saline water beetle Potamonectes cerysyi is particularly widespread (Pesce et al. 1981). Among Ephemeroptera, Cloeon dipterum is most common.

8. Vertebrates

No vertebrates venture into the Chotts themselves, but four fish species are native to the fringing oases: the cyprinid Barbus antinorii, the Cyprinodont Aphanius fasciatus and the cichlids Hemichromis bimaculatus and Haplochromis desfontainesi (for which Tozeur is the type locality). Rana ridibunda perezi and Bufo viridis represent the Anura, while Mauremys caspica leprosa has been found in the Oued Gabes and probably occurs in the Chott area as well. Some species of fish have been introduced to the area (see below).

9. Human activity and management

Traditionally the area around the Chotts, because rich in springs, was exploited for palm tree production and irrigated for horticulture. These activities are still extant and have gradually been modernised. Mosquitoes and bilharzia were major health problems. Gambusia was introduced to control the former, although Seurat (1938) criticised this action at an early date and suggested that the local Aphanius should be used for the same purpose. Gambusia has now declined in many oases, but so has the local invertebrate fauna. In addition to the intensive use of insecticides, molluscicides have been applied, and Bulinus has regressed to the point of posing no major threat to public health. Beside Gambusia, common carp has been introduced into some oasis pools e.g. at Douz.

The major stress on the fringing belt of oases is, however, tourism. Within 20 years the oases of Nefta and Tozeur have expanded from big villages to sizeable cities. Although it peaks in summer, tourist activity has now become perennial. There are, as a consequence, serious problems with waste disposal, and most sewage is released directly into some seguias. Another problem is that expanding settlements encroach directly upon the aquatic ecosystems. At Nefta, a major part of the local Typha-marshes have been filled in and destroyed.

A special threat hangs over the hot springs of El Hamma, type locality and sole site of Thermosbaena mirabilis. Of the three springs that harbour it, el Baama was blocked in 1950 and Ain sidi Abd el Khadr was being rebuilt in 1976. The main site, the ancient public baths of Ain el Bordj, were under restoration in 1983. No specimens have been reported in the literature since 1976. In that year, Thermosbaena had become rare at Ain el Bordj, a consequence of the periodic disinfection of the springs. Another factor is the use of detergents in the baths, which flocculate with organic debris and block the cracks in the underwater walls that are the habitat of Thermosbaena.

2.5. NIGER: AIR AND TENERE

2.5.a. BAGHZAN GUELTAS

1. Geology and morphology

The Air mountains are geologically similar to the Hoggar, and are part of the Precambrian (suggarian), granitic Saharian shield. Some volcanic activity persisted until the Holocene, and young (uneroded) stratovolcanoes occur in several places. Morphologically, the Air is a peneplain (400-700 m asl), above which a number of more or less circular table-mountains emerge, consisting of a crystalline core covered by basalt of Pleistocene age. Rivers (= kori) that drain those mountains have eroded their flanks and produced canyons that offer good conditions for the preservation of surface water. Gueltas and springs are found in even larger numbers in the Air than in the Hoggar. The Baghzan massif is the southernmost of the circular table-mountains. The peneplain at its base is at an altitude of c. 800 m, while the plateau itself is at c. 1500 m. Impressive canyons are found along its eastern flank. For example, the canyon of Nabarou (17°39'N, 8°49'E at its mouth) is an almost perfect vertical incision into the mountain wall, and contains an elongate (several hundreds of meters in length) guelta that is only a few meters wide. The canyon of Ighalabelabene (or Irabelabene), slightly further north (17°42'N, 8°49'E), is V-shaped and gueltas and springs lie scattered along its length (8 km). On top of the table mountain there is a dry lake bed (Egharghar) which consists of a thick layer of subfossil molluscs (17°49'N, 8°43'E). The kori Nabarou and the kori Telouess (draining Ighalabelabene) merge to form the kori Taghas on the peneplain. The bed of this oued is up to 2 km wide. It is fairly wooded on its sides, in places even forming a forest.

2. Climate

The Air is situated on the transition between the Sahel, with a tropical savanna climate, and the hyperarid Sahara. It shows a steep N-S gradient in annual precipitation over a distance of less than 300 km. The Baghzans are part of the southern Air, and their climate is similar to that of Agades (500 m). Mean annual temperature is 27.8°C. May is the hottest month (mean maximum of 41.8°C, mean minimum 24.6°C). December is the coldest month (max. 28.8°C, min. 10.6°C, abs. max. 33.8°C, abs. min. 5.8°C). Precipitation average for 1922-1960 , 170 $mm.a^{-1}$, peaks sharply in July-August-September and is thus distinctly monsoonal. 90.5 mm (i.e. 55% of the total) falls in August alone, and 90% falls in the three monsoon months combined. The koris flow as soon as more than 5 mm falls in one rainstorm. As in other semi-desert areas, there is strong variation between years e.g. 116 mm in 1957 and 287 mm in 1978.

Winds from the E. dominate from September till June, but monsoon winds from S to W take over in July-August. As a consequence, the western flanks of the Air receive much more rain than the Eastern side, which faces the Tenere.

3. Water chemistry

Some (incomplete) analyses were performed on water from Canyon Nabarou (Aguelmam Tamalaka) and from Ighalabelabane gorge (Aguelmam Thathefit, In Garzamane, and Eghadienn d'Alah). They indicate a low mineral content. pH values were acid to neutral (5.2 - 7.0).

$meq.l^{-1}$	Na	K	Ca	Mg	Cl	Cond. $10^{-6}S.cm^{-1}$
Nabarou: Tamalaka	0.2	0.5	1.1	0.7	1.1	470
Thathefit	0.2	0.2	0.4	0.5	1.1	180
In Garzamane	0.4	0.2	0.9	0.1	1.4	170
Eghadienn d'Alah	0.2	0.1	0.5	0.2	1.4	156

4. Macrophytes: No aquatic macrophytes were noted.

5. Phytoplankton

A detailed study of the algae from this area was carried out by Compère (1980), who lists 530 taxa from 34 localities. The Ighalabelabene gueltas, which were sampled shortly after the monsoon rains of September 1977, were dominated by Volvocales: *Volvox* spp, *Eudorina elegans*, *Pandorina morum*, *Gonium pectorale* and *Chlamydomonas* spp; *Sphaerocystis schroeteri* was also abundant. *Nitzchia palea* was the dominant diatom, accompanied by *Cymbella hustedtii* f. *stigmata* and *Stauroneis anceps*. In some gueltas, and in the dammed up spring Thagar, filamentous green algae of the genera *Ulothrix*, *Stigeoclonium*, *Oedogonium* and *Spirogyra* were found, along with the diatoms *Synedra ulna* and *Navicula confervacea*. In Nabarou canyon, Cyanobacteria were the dominant group, with *Lyngbya majuscula* the main species, but otherwise the same filamentous green algae, desmids, and diatoms as in Ighalabelabene.

6. Invertebrates

Bulinus truncatus (Fischer-Piette 1950) is the only recent mollusc so far recorded from the Baghzans; Crustacea are represented by Streptocephalus torvicornis (Monod 1950). Triops granarius and Caenestheriella crinita were abundant in the lower gueltas in September 1977, accompanied by Metadiaptomus mauretanicus, Neolovenula alluaudi and Paradiptomus greeni. The following dragonfly species occur: Anax imperator, Orthetrum brachiale, Trithemis arteriosa (Fraser 1950). In addition, Dumont (1978) recorded Ischnura saharensis, Orthetrum chrysostigma and Pantala flavescens. A list of water beetles is given by Guignot (1950). It includes Hydryphus africanus, Guignotus major, G. angularis, Rhantaticus congestus, Eretes sticticus, Dineutes alreus and Gyrinus regimbarti. All are Afrotropical except the last which is of Palaearctic origin. Poisson (1950) cites the following Afrotropical Hemiptera: Laccocoris limogenus, Enithares sobria, Anisops debilis and Sigara hoggarica.

7. Vertebrates

No fish occur. The only amphibian cited from the Baghzans is Bufo regularis. In September 1977, it was extremely common in all koris immediately after rain showers. There is a doubtful record of Mauremys leprosa from Agades (2 specimens) (Chopard & Villiers 1950).

8. Human activity and management

There are some small Tuareg villages on top of the Baghzan plateau. Mule caravans regularly travel up and down the gorge of Ighalabelabene for trade with Tabelot, the main village on the peneplain. The gueltas are not exploited for any particular purpose and only the dammed-up spring of Thagar is used for local irrigation.

2.5.b. TIMIA

1. Geology and geomorphology

The kori Timia (18°06'N, 8°46'E) drains the E. flank of the table mountain Adrar Egalah, which is covered by a thick layer of basalt. On the S-E flank a fault across its bed causes the underflow to form a spring, which has eroded a narrow, cascading canyon through the basalt, and ends up in a large (30 m across), circular guelta fed by a perennial waterfall. Inside the gorge, numerous small plunge-pools are found. This is the area known as Timia. Its climate is intermediate between that of Agades and Iferouane (see below), but no data were available to the present author.

2. Water chemistry

An analysis of the water of the guelta (b) and of a nearly dry pool downstream (a) is given below. Both are in the oligohaline range, but a concentration effect is obvious in the pool. Salts, however, do not accumulate at Timia, because several floods occur each year and wash them away.

$meq.l^{-1}$		Na	K	Ca	Mg	HCO_3	Cl	SO_4	Cond. $10^{-6}S.cm^{-1}$
Timia	a	4.6	1.3	1.5	0.4	1.5	2.5	1.4	880
	b	0.4	0.4	1.5	0.07	0.8	0.9	0.2	150

3. Macrophytes

In March 1976 and May 1980, the main guelta was richly overgrown with Potamogeton spp. Above the main fault lies the oasis of Timia, an extensive date-palm plantation. It contrasts with Hyphaena thebaica, the native dum palm of the area, which is widely distributed along the edges of all main koris.

4. Algae

Compère (1980) found an abundance of filamentous green algae (genera Oedogonium, Mougeotia, Spirogyra), accompanied by numerous Cyanobacteria, a few flagellates, and some green algae. The most abundant diatoms were Rhopalodia gibberula, Anomoeoneis sphaerophora, Synedra ulna and Amphora ovalis var. pediculus.

5. Invertebrates

Bulinus sp. abounds in the guelta. No comprehensive inventory of aquatic insects is available except Odonata. The damselfly Ischnura saharensis is noteworthy, but also the desert gomphus, Paragomphus sinaiticus. The zooplankton is rich and varied, and consists of Streptocephalus torvicornis, large calanoids, Daphnia and numerous small chydorids. An as yet undescribed groundwater Isopod (family Microcerberidae) occurs at the spring.

6. Vertebrates

There are no species on record, but the toad Tomopterna cryptotis occurs at Elmeki, to the North, and its presence at Timia is therefore probable.

7. Human activity and management

The permanent village of Timia is situated above the fault, a few kilometers upstream of the gueltas. The latter are of no direct use to the community, which irrigates the edges of the valley from numerous wells in the kori. Bilharzia, which has a high incidence among the Tuareg of Timia, is an important health problem.

2.5.c. THE TAMGAK GUELTAS

1. Geology and geomorphology

The Adrar Tamgak (c. 19-19°25'N, 8°30'- 8°50'E) is the major mountain massif of the north-eastern Air. It is entirely granitic, and faces the Tenere plain to the East. The plateaux are around 1600 m, with peaks close to 2000 m. To the West, it is bounded by the Air peneplain, with a mean altitude of 600-650 m. One major kori, the kori Tamgak, has cut a deep, weakly crescent-shaped, E-W oriented, canyon across the massif. It springs at about 1450 m, close to the eastern wall of the Adrar Tamgak, and is augmented on its westward course by numerous short side-canyons. Some of these have also cut steep gorges. One major tributary, the kori Zakkat, joins up with the kori Tamgak in the West, at an altitude of 680 m. It is North-oriented, and springs at about 1600 m. West of the junction, the kori is called Ougourou. It winds through a wooded depression, in places over 2 km wide, and carries a rich supply of groundwater. This has attracted several Tuareg settlements, the largest of which is Iferouane. The Tamgak system has a major concentration of gueltas and springs. About 50 of them are more or less permanent, but only a few have been explored. The kori Tamgak only flows periodically, except in depressions, where the ground water flow surfaces over distances of 50-100 m (e.g. Teguiddamo). Other spring-like situations are seepages from the side-walls of the gorge (e.g. Aboubdoub). Most common, however, are typical gueltas in deep, steep-walled canyons, and plunge-pools (e.g. Agoum).

2. Climate

Yearly precipitation at Iferouane (680 m) is 63.2 mm, slightly more than one third of the amount recorded at Agades. Rainfall still peaks in July-August-September, with a maximum of c. 30 mm in August alone, but the overall conditions are clearly desertic. The influence of the monsoon is well defined but weak. This tendency is also reflected in the temperatures, especially the daily ranges and the minima which are, respectively wider and lower than at Agades. The highest temperatures occur in July (41.1°C), while January is the coldest month, with an absolute minimum of 1.5°C, and a mean minimum of 7.5°C. Night frost is not exceptional in December and January.

3. Water chemistry

Samples collected in March 1977 disclosed a very weakly mineralised water in different sectors of the gorge. The water chemistry of the kori Ougouri wells at Iferouane is not very different from that of the sheltered gueltas, while even the exposed gueltas (Teguiddamo) are only slightly more concentrated than the groundwater, presumably as a consequence of their flowing nature.

$meq.l^{-1}$	Na	K	Ca	Mg	HCO_3	Cl	SO_4	Cond. $10^{-6}S.cm^{-1}$
Iferouane								
(-20 m)	0.6	0.3	1.9	0.4	1.7	0.9	0.6	245
G. Agoum	0.3	0.3	1.4	0.5	1.1	0.7	0.4	152
G. Teguiddamo								
1	2.3	0.5	2.7	0.8	2.8	1.1	1.2	360
2	1.0	0.4	3.4	0.2	2.5	1.1	1.0	360
G. Aghagha	0.8	0.8	2.4	0.7	1.6	0.9	1.1	255

4. Macrophytes

Agoum is devoid of Macrophytes; extensive Typha-meadows surround the gueltas of Teguiddamo and Aghagha. In the open water of the latter, Potamogeton spp. are abundant.

5. Algae

Compère (1980) found Chara globularis, C. braunii and an aquatic liverwort, Riella cf. cossonii in guelta Agoum, besides flagellates, Cyanobacteria, Chlorophycea, and more than 40 species of diatoms. Anomoeoneis spaerophora, Nitzschia levidensis and N. cryptocephala var. exilis were the dominant species. In Teguiddamo, Chara globularis and C. zeylanica occurred, besides large cyanobacterial colonies such as Dichothrix orsiniana and Scytonema figuretum, numerous large filamentous green algae (Draparnaldiopsis alpina, Dichothrix tibestica, Zygnema airense, mucilaginous plates of Tetrasporidium javanicum) and a host of small species e.g. Synedra ulna, Rhopalodia gibba, Achnanthes exilis, Nitzschia amphibia and Navicula minima. The seep of Aboubdoub is coated with filaments of Oedogonium, Mougeotia, Spirogyra and Rhizoclonium hieroglyphicum, accompanied by Cyanobacteria and diatoms (e.g. Epithemia argus, Achnanthes exilis, Navicula cryptocephala, Cymbella microcephala and C. delicatula. The Aghagha pools are rich in larger forms such as Chara braunii f. perrotetii, Cladophora glomerata, Oedogonium spp., Spirogyra spp., Lyngbya majuscula and small diatoms (Cocconeis placentula, Nitzschia amphibia, Synedra ulna, Amphora ovalis var. affinis, A. ovalis var. pediculus and Navicula minima).

6. Invertebrates

No data on Hemiptera, Coleoptera, or Ephemeroptera have been published, although these groups all have representatives in the canyon. Remarkable dragonflies are Ischnura saharensis, Paragomphus sinaiticus, and Orthetrum ransonneti. The open-water plankton of Agoum is dominated by Anostraca, large Calanoids and large Daphnia; the weedy Teguiddamo and Aghagha have numerous Chydorids, but not the genus Chydorus s.s. Instead, Oxyurella tenuicaudis and Pleuroxus aduncus abound. Bulinus truncatus (Mollusca) is found nearly everywhere.

7. Vertebrates

No aquatic vertebrates have as yet been reported from Tamgak canyon.

8. Human activity

Tamgak canyon is not permanently inhabited, but Tuareg pastoralism in the valley is common.

2.5.d. DJADO, FACHI AND THE KAOUAR OASES

1. Geology and geomorphology

This area (c. 18-21°N, 11-12°5'E) belongs to the Lake Chad drainage basin. Geologically, its outcrops become younger from the North to the South. The plateau of Djado is of Palaeozoic, mainly Devonian age, while the cliffs at Bilma and Fachi are Cretaceous. Further South, at Agadem and in the isolated massif of Termit, rocks of tertiary age are found. The major part of the basin (the Tenere plain) is covered by wind-blown Pleistocene sand-dunes. During the late Pleistocene and Holocene, important lacustrine phases occurred in this currently hyperarid region. At Bilma, for example, there is evidence for lake formations older than 40,000 BP, while there were lacustrine episodes at Fachi around 22,000 BP, 8,500 BP, and again around 3,500 BP. The Kaouar cliffs, North-South oriented, face the Tenere to the West, and have a string of oases watered by numerous natural springs at their feet, augmented by man-made wells. The springs presumably draw water from the continental intercalaire sensu Killian (1922). Each year the discharge of the Bilma springs increases in November, approximately four weeks after the monsoon rains start in the Tibesti. This suggests that the watertable is recharged, through the underlying sandstone, with water percolating into the continental intercalaire at the foot of Tibesti. During this century the artesian pressure on the deep groundwater has produced, largely through human intervention, some artificial lakes in the area. First the lake of Arrigui, North of Dirkou was created. In 1981, a borehole drilled near the bordj (fort) of Bilma, began inundating the depression and could not be stopped, in spite of efforts to close it by explosions (E. Schulz, pers. commun.).

The Pleistocene and Holocene lakes in the Kaouar area were of the piedmont type, and derived water from precipitation, runoff from the cliffs behind them, and from a water table higher than today. Some of the deeper depressions have since evolved into brine pools (salines), e.g. at Bilma and Fachi, where salt is still exploited on a commercial scale. It is exported by camel caravans to the Air and marketed at Agades.

2. Climate

The climate of the Tenere is a true desert climate, although the South is increasingly under the influence of the summer monsoon. In the Djado-Bilma area yearly rainfall is about 10-20 $mm.a^{-1}$ (but 10 $mm.a^{-1}$ in the Tenere proper; 22 $mm.a^{-1}$ at Bilma). Several consecutive years without any precipitation are no exception. Bilma has an average of two rainstorms per annum. The sky is totally free of clouds for about 90% of the time and, while in July-August mean monthly temperatures of 45°C have been recorded (e.g. at Bilma), temperatures may drop to well below freezing in December-January (-6°C), with daily temperature amplitudes of 25° or more. Under these circumstances annual evaporation is c. 6 m. Strong winds, accompanied by dust storms, predominantly from the NE-sector, occur during winter.

3. Water chemistry

The chemical composition of the waters of the Djado-Kaouar area varies tremendously from place to place. Most of the natural springs, like Midjigatene (356 m, 18°36'N, 12°57'E), and the springs at Bilma itself (350 m , 18°42'N, 12°55,E) are fresh, but at the other extreme Kalala, the saline of Bilma (now flooded) is a saturated brine. The lake at Arrigui (19°05'N, 12°55'E) and the pools at Djado (the latter of natural origin) (21°01'N, 12°17'E) are saline, but with a chemical composition that varies strongly with water level and season. Man-made wells in the Tenere tend to be found in depressions, and usually contain salty water. The isolated well of Tiguedelane (18°32'N, 12°28'E) is rich in sodium carbonate, while the well of Kao Saoua South of Fachi (18°04'N, 11°36'E) is reputedly loaded with magnesium salts.

4. Macrophytes

The lakes are fringed by Typha meadows (T. australis and T. elephantina), occasionally mixed with Phragmites australis. These in turn are surrounded by grasses (Desmostachya bipinnata, Imperata cylindrica, Saccharum ravennae) associated with Tamarix brachystylis. Seventeen species of submerged waterplants have been cited from this area, 14 of which are also found in the Borkou oases (see 2.7: Chad), but Pistia stratiotes, Panicum longijubatum and Jussiaea erecta are limited to the Kaouar oases. Heleocharis tibestica is endemic to the area (Monod 1950; Quézel 1965).

5. Algae

Few data are available. Compère (1967) provides a list of 19 species collected in an unspecified waterpoint with neutral pH near Segueddine (20°12'N, 12°59'E) North of Bilma. Diatoms were dominant (15 species), and there were only 4 species of Cyanobacteria.

6. Invertebrates

Not much is known. Jacquemart (1974) studied the Collembola that occur in the wet areas around the pools of Djado and Arrigui (mainly Seira spp.). The dragonfly Ischnura saharensis has been cited from Djado, and Sympetrum fonscolombei and Crocothemis erythraea occur at Bilma (Dumont 1982). The plankton is not known in sufficient detail. A saline cyclopoid copepod of oriental origin, Apocyclops dengizicus has been collected at Djado and Bilma (Dumont 1979), but in the same area Daphnia magna also occurs.

7. Vertebrates

There appear to be no native aquatic vertebrates in this area, although some Anura could live at Djado: Oreochromis aureus has been introduced at Bilma.

8. Human activity

The salt works at Salala (Bilma) are famous throughout the Sahara. Traditional irrigation and garden culture is the main activity of the Kaouar oases.

2.6. THE LIBYAN DESERT (Coastal Libya is in Region 1)
(Fig. 2.5)

2.6.a. GHAT REGION (Ghat, El Barcat, Habschat, Feuet, Tounin, Tin Djeraben)

1. Geography

Ghat is situated 80 km NE of Djanet, at 640 m asl. (25°N, 10°25'E). It lies at the outer rim of the Inner Tassili and on the western edge of a wide Southwardly oriented valley that belongs to the Intra-Tassili fork. At the E. and S. of the city itself, there are gardens watered by 20 natural springs and a large number of wells. There are about 9000 palm trees in Ghat. The small settlement of Tounin (c. 250 inhabitants) lies 1 km to the W. and has 4500 palm trees and 15 springs. Tin Djeraben has 3 small, permanent, spring-fed lakes; Habschat has a single spring-fed lakelet, and El Barcat, c. 12 km S of Ghat has numerous pools and swamps, in addition to two larger ponds. Feuet, East of Ghat, has 3 springs and pools, including the so-called round spring.

2. Climate

At Ghat it is the same as for Djanet (refer to section 2.3.c).

3. Water chemistry

Most of the springs and pools in the Ghat area are considered to have fresh water, except for the temporary inundations of the Sebkha of Ghat which collect after rainstorms. An analysis of major ions performed on samples collected in June 1978 confirms this:

	Na	K	Ca	Mg (meq.l^{-1})	HCO_3	Cl	SO_4	Cond $10^{-6}S.cm^{-1}$
Major pool of El Barcat	0.7	0.04	2.0	0.7	2.3	0.9	0.2	185
Ghat: pool	1.3	0.01	2.2	1.4	3.0	1.2	0.4	412
Ghat: artificial basin	1.2	0.01	2.0	0.7	1.3	1.7	0.3	252

4. Macrophytes

The shallow eutrophic pools all tend to be invaded by macrophytes. The uncommon Terpsinoe musica, rather steno-ionic of freshwater and typical of Northern Saharan areas, is found at Habschat and El Barcat. At all other sites there is an abundance of Phragmites australis, Typha spp., Juncus spp., Potamogeton spp. and Utricularia spp.

5. Algae

Marchesoni (1947), in a study of the algae of the Fezzan and of Ghat, stressed the algological richness of the Ghat area, and found an abundance of Diatoms, Protococcales, Cyanobacteria and other groups. In all, he recorded over 210 species. Chara spp. abound in many of the pools.

6. Invertebrates

There is a rich assemblage of Hemiptera, Coleoptera, Diptera, Ephemeroptera and Odonata related to that of the Tassili-n-Ajjer, but even more diverse, and with the Afrotropical element even more dominant. For example, among the Odonata Pseudagrion hamoni and Agriocnemis sania occur. The Mollusca seem to be represented by only 3 species: Melanoides tuberculata, Biomphalaria pfeifferi and Bulinus truncatus. The zooplankton of the pools that contain fish, or to which fish have been introduced, are poor in species, but in some temporary pools adjacent to the permanent ones, Triops granarius and probably large euphyllopods are common.

7. Vertebrates

Two fish species are native to the area, and Clarias lazera lives in at least two oueds North of Ghat. El Barcat is the type locality for Barbus deserti but it also occurs at Ghat itself. Hemichromis bimaculatus also occurs in two ponds at El Barcat, and in two ponds at Feuet. However, Gambusia has been introduced to almost all oasis waters, even including shallow wells, and has greatly impoverished the original biocenoses there. Amphibia include Rana ridibunda perezi, Tomopterna cryoptotis, Bufo regularis and Bufo viridis.

8. Human activity and management

Ghat is inhabited and the surrounding oases have attracted permanent settlements and oasis agriculture. Malaria and bilharzia used to be major health hazards in the area. The introduction of Gambusia in the 1930s and the later extensive use of insecticides have solved the malaria problem, but have probably extinguished many non-dipterans as well (e.g. in 1978 none of the Zygopteran species present in the 1930s were found). The expanding city of Ghat also encroaches upon the marshes of the oasis itself and at El Barcat, the type locality of B. deserti had been temporarily drained in the 1970s, and transformed into a cemented basin. Whether the fish still occurs there is unknown.

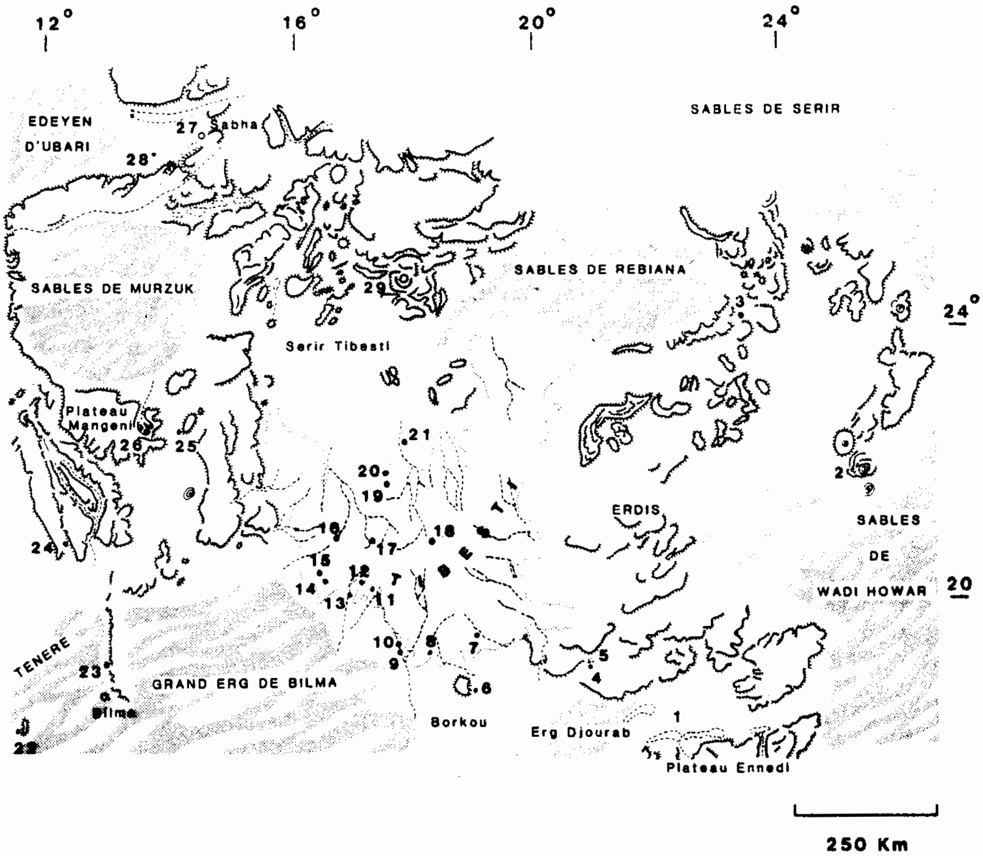

Fig. 2.5 Locations of permanent and ephemeral surface waters in the Central-Eastern Sahara. 1-Sebkhas of the Mourdi Depression, 2-Jebel Uweinat Gueltas, 3-Lake Kufra, 4-Lake Yuan, 5-Lake Ounianga, 6-Tigui Guelta, 7-Yi Yera Guelta, 8-Tougouma Guelta, 9-Oudingue Guelta, 10-Totous Guelta, 11-Maro Guelta, 12-Goy Guelta, 13-Sherda, 14-Mourso Guelta, 15-Orungi Guelta, 16-Trou au Natron Guelta, 17-Sobouroum Hot Spring, 18-Yebbi bou Spring, 19-Aozou Guelta, 20-Yomadji Guelta, 21-Kayougue, 22-Fachi, 23-Lake Arrigui, 24-Small Lakes of Djado, 25-Toummo Spring, 26-Guelta of the Oued el Kebir el Garegh, 27-Lakes of Ramlat Dawada, 28-Mandara, 29-Crater of Wau en Namus.

2.6.b. THE LAKES OF THE RAMLET DAWADA

1. Geography

The erg of Ubari is one of the large, late-Eocene to Pleistocene sandseas of the Fezzan. An eastern extension (the Ramlet Dawada), West of the city of Sebha (27°04'N, 14°05'E) and NE of Ubari, contains a series of permanent salt lakes in depressions between the sand dunes, where the groundwater table touches the surface. The groundwater even seems to emerge under some pressure (Schiffers 1950). The positions, surface area and nomenclature of the lakes vary on different maps (Monod 1969). Desio (1937) estimates the total number of lakes and pools, concealed in the dunes of Ramlet Dawada, at 10. Mandara, the largest, has a diameter of c. 300 m. It is roughly oval in shape and very shallow. Another, Oum-el-Ma, is elongate, lens-shaped, and probably several meters deep. All these lakes (Mandara, Oum-el-Ma, Bahar-et-Truna, Bahr el Dud = Gabr Aoun, Oum el Hassan = Tademka, Nech Nuchia...) are closed basins and saline.

2. Climate

The climate at the lakes is the same as that of the nearby city of Sebha. June is the hottest month (average 32.3°C), and January the coldest (11.2°C). Mean annual temperature is 22.9°C. Daily temperature amplitudes may reach 25°C. The lowest temperature recorded is 0.1°C in January 1931. It may thus occasionally freeze at ground level. The hottest temperatures recorded are in the range of 49°C (July 1932, Murzuk). Relative humidity is about 28-35% in summer, increasing to 50% in winter. Winds are from the NE-sector throughout the year, occasionally turning to East. Cloudiness is rare and only during April-May does some cloud cover occur. Rainfall is 10 $mm.a^{-1}$ and totally rainless years are not uncommon (on average 1 per 12 years). Wide variations are the rule (e.g. in the 1930s no rainless years were recorded and precipitation varied between 6.8 and 30.3 mm).

3. Water chemistry

Bellair (1945) showed that the differences in salinity among the lakes span two orders of magnitude. The water of Tademka is mesohaline, but Nech Nuchia at the other extreme is a saturated brine. Some of Bellair's results, taken from Monod (1969), are presented below:

	Na ($g.l^{-1}$)	Cl ($g.l^{-1}$)	residue at 180°C ($g.l^{-1}$)
Gabr Aoun	32.36	41.53	100.1
Mahfou	26.13	35.67	77.8
Tademka	1.81	2.19	5.2
Oum el Hassan	39.40	71.35	124.8
Trouna	63.27	53.60	161.2
Nech Nuchia	164.16	183.18	416.5
Fredgha	58.26	23.60	144.4

Another analysis carried out on samples collected from lakes Mandara and Oum-el-Ma in June 1978 is given below.

$meq.l^{-1}$	Na	K	Ca	Mg	HCO_3	Cond. $10^{-6}S.cm^{-1}$
Mandara:						
freshwater swamp	6.1	0.9	6.4	2.4	5.9	2565
main lake	218.3	88.2	3.1	73.8	9.9	$>10^4$
Oum el Ma:						
main lake	100.6	32.8	14.8	82.6	7.3	$>10^4$

The spring-fed swamp around Mandara is fairly fresh, but the open water is at saturation point, and continuous precipitation of salts can be seen.

4. Macrophytes

None recorded. The springs and wells that surround the lakes support extensive date palm plantations.

5. Algae

No records. Characeae abound in the freshwater swamps around Mandara, and filamentous green algae with associated diatoms are plentiful there as well but have not yet been studied taxonomically. Possibly, the liverwort Riella occurs in Gabr Aoun (Monod 1969), while Dunaliella and Nostoc are supposed to live in the Artemia-lakes.

6. Invertebrates

The lakes of the Ramlet Dawada are famous because some of them (e.g. Gabr Aoun) contain the brine shrimp Artemia sp., originally described from here as Artemia oudneyi Baird. It co-occurs with the fly Ephydra macellaria. In Mandara, larvae of Stratiomyid dipterans are also found. In the low-salinity springs and marshes, waterbugs, dytiscid beetles and dragonflies occur. A significant species is Ischnura fountainei, typical of spring environments in deserts and semideserts. The gastropod Bulinus truncatus is also found here (Van Damme 1984). The zooplankton is rather poor, and consists of small cyclopoid copepods (Cryptocyclops linjanticus, Paracyclops affinis) only.

7. Vertebrates

No fish occur. Anura were seen at Mandara (pers.obs) but none were captured.

8. Human activity and management

The small human communities that inhabit the oases fringing the lakes are negroid and seem to be of Kanuri descent. They may have retreated into the dunes of Ramlet Dawada at the end of the neolithic humid spell (c. 5000 B.P.), when the oued Tafassasset, which united the

Tassili-n-Ajjer to Lake Chad, dwindled and finally dried up. They survived here, adapting to a unique diet of animal proteins, i.e. dried Artemia-cakes. The plankton nets used for fishing are made, and the fishing is performed only by the women. The name DAWADA, given by the surrounding Arabs to the lake people, is derived from dud, or worm, and refers to this remarkable example of human ecology. The dawada people distinguish between different types of "worms". A red type, highly valued (douda), and a pale type, of lesser quality (takerouka) are recognised, corresponding to a dominance of Artemia or of Ephydra, respectively. An alga (danga), whose taxonomy is still uncertain is mixed with the worms while they dry in the sun. An analysis of the cake was published by Monod (1969), who found it to be rich in essential amino-acids. This diet of "douda" is supplemented by dates. Apart from this unique symbiosis of man and lake, bilharzia is a health problem in this area.

2.6.c. WAU EN NAMUS

1. Geography

The crater of Wau en Namus, situated 150 km SE of Wau el Kebir (24°54'N, 10°43'E), is about 5000 years old. It is a very young volcano and the most Southeasterly of the eruptive chain in the Djebel el Haroudj region of Central Libya. It is situated on a flat stony plateau, or Serir, and surrounded by an elliptic ring of black lapilli which encircle the crater opening over a distance of 5-10 km (Pesce 1960). The crater itself, sunk into the Serir, has a diameter of 4 km. A volcanic cone, 120 m high, stands in its centre and is surrounded by three large and two small lakes. The total surface area of these lakes is c. 320,000 m^2 and their altitude 434 m a.s.l. The volcano itself may still have been active in historic times, and there is a hotspring in one of the major lakes, an indication of residual volcanic activity. The lakes are saline, fed by groundwater and surrounded by numerous freshwater springs. Digging a 1 m hole in the bottom of the crater suffices to reach the groundwater in most places. In spite of the strong local evaporation (see below), the major lakes vary little in area, but the small lakes may occasionally dry up. Due to a lack of continuous observation, the magnitude and rhythmicity in water level variation is, however, uncertain. Desio and Richter found the so-called "red-lake", one of the 2 smaller water bodies, dry in 1931 and 1942, but it was full in 1940, 1955 and 1958. There are no climatic observatories in the immediate vicinity of Wau an Namus, but yearly precipitation can be estimated at 5 mm. a^{-1} maximum, and temperatures are similar to those at Sebha. Richter (1958) estimates the yearly evaporation to be a minimum of 5 m.a^{-1}, and calculates a yearly water loss from the lakes to the atmosphere of 1.6 $10^6 m^3$. With a possible age of 5000 years, this explains why they have become saline.

2. Water chemistry

Desio (1937) states that the brines are NaCl-dominated. Schwabe & Simonsen (1961) found a total residue at 180°C of 175.6 g.l^{-1} in the main Southwestern lake (= lake 3; 14.6 ha, max. depth 12.5m shape triangular), and the following ionic composition: Cl 53 g l^{-1}; Na + K 97.7 g l^{-1}; Ca 106 mg l^{-1}; Mg 527.8 mg l^{-1}; SO_4 31.4 g l^{-1}.

3. **Macrophytes**

The lakes are extensively fringed by Phragmites which, in lake three, occupies an area of 3.3 ha. There is no information on other hygrophytes. An oasis of wild date palms, intermixed with Tamarix nilotica, adds to the beauty of the lakes' scenery (Jany 1969)

4. **Algae**

Schwabe & Simonsen (1961) studied the Diatoms (22 spp) and Cyanobacteria (4 spp) from lake 3. Among the diatoms about equal numbers of strongly euryhaline oligohalobionts, euryhaline mesohalobionts and polyhalobionts were identified. No doubt this inventory is in need of updating. No information on the other lakes has become available. The "red lake" may derive its colour from purple bacteria, Dunaliella, or both.

5. **Invertebrates**

The damselfly Ischnura saharensis has been reported from the crater of Wau en Namus (Aguesse 1958), but the oasis derives its name from the huge swarms of mosquitoes (namus = mosquito) that make life for warm-blooded vertebrates a torture here. Possibly, this is why the oasis is uninhabited. No Mollusca or Crustacea seem to have been collected here so far.

6. **Vertebrates**

No records, except for waterfowl, which commonly visit the lake edges.

7. **Human activity and management**

Wau en Namus lies on the caravan route between Sebha and Kufra, and was an important water point between Wau el Kebir and Tazerbo. The latter function has now greatly declined, as caravans have become rare. Although the oasis is not inhabited today, Shiffers (1950) thinks that at some earlier date, there was a permanent settlement of Tibu people in the crater.

2.6.d. KUFRA

1. **Geography**

The oases of Kufra (24°12'N, 23°18'E) are situated in the NE-corner of Sarra, a low plateau of Nubian sandstone in eastern Libya. Kufra itself occupies a flat, oval basin of Nubian sandstone, and is surrounded on all sides by low mountains and hills (400-600 m high). The E-W diameter of Kufra basin is 110 km, the N-S diameter only 60 km. To the W. extend the sands of the Rebiana desert. The groundwater table is close to the surface throughout this area, and lakes are found in depressions in the Rebiana erg, as in Bzema and Rebiana oases, but no details of them are available. In Kufra area (El Giof, and surrounding villages), there is a series of small, usually saline (predominantly natron) lakes.

Salinity appears to vary strongly between lakes, some being surrounded by a salt crust, and others not (Compère, 1967). These differences are similar to the situation described for Ramlet Dawada, and perhaps for the same, not yet fully understood reasons. J. Léonard (in Compère, 1967) sampled two lakes at Goudouie, El Giof. These are presumably not the two lakes discussed by Desio (1938), and called Hafun (389 m a.s.l., 46,800 m^2 area, max. depth 3.8 m, bottom covered with Na_2SO_4 crystals; hypersaline to the extent that man floats in them) and Buema (383 m a.s.l., 39,500 m^2 area, 2.8 m max. depth; bottom grey, saline, hypersaline). The inventory of the surface waters of Kufra is hence in need of updating. All, however, derive their water from the underlying, Palaeozoic groundwater table.

2. Climate

Precipitation is extremely low (1.9 $mm.a^{-1}$), and 1 year out of every 2.6 is completely rainless. The maximum precipitation ever recorded is 12.5 $mm.a^{-1}$. Temperatures peak around August, with monthly averages of c. 31°C. Maxima exceed 45°C in July quite regularly. Minima are reached in January and February, and are about 12-13°C. Absolute minima, in these same months, may descend to -2°C. Cloudiness is extremely low, and potential evaporation is close to 6 m. a^{-1}.

3. Macrophytes

In lake 1, Compère notes a bottom meadow of Ruppia maritima, and a fringe of Cyperus laevigatus, mixed in places with Phragmites communis along the wet margins of the lake. Behind this fringe, in drier places, a second girdle of Juncus maritimus and finally stands of palm trees and Tamarix occur. The lakes studied by Desio (1938) were also broadly surrounded by reeds.

4. Algae

Compère (1967) lists algae collected in two pools at Goudouie, El Giof. Lake 1 (saline) contained numerous filamentous (Oedogonium, Zygnema) and unicellular algae (70 species), most of which were euryhaline freshwater species (unfortunately, no chemical analysis of this site is available). In lake 2, Chara vulgaris also occurred.

5. Invertebrates

There is little reliable information on aquatic insects. Navas (1931) gives a list of Odonata which includes Ischnura senegalensis. No recent Mollusca are on record, but Bulinus may be expected here. Desio (1938) states that Lake Hafun was very rich in plankton, but his samples have been lost. In samples collected by Léonard, some unusual Crustacea were found. These include Chydorus sphaericus, a cladoceran not found in the Sahara except here and in the Tibesti, and the calanoid copepod Tropodiaptomus incognitus, a species typical of Lake Chad (Dumont & Verheye 1984). The large Cladoceran Daphnia magna has also been found, an indication that vertebrate predators are absent. The exact collecting sites of all these species are unknown; it is unlikely that they were found in the open water of the saline lakes. Rather, they would be expected in the outflows of the springs that feed the lakes, which locally form freshwater puddles, large enough to permit their survival.

6. **Vertebrates:** None recorded. Some Anura should occur.

7. **Human activity and management**

There are several villages in Kufra area. The traditional oasis functions are supplemented by that of an important market place, because Kufra is at the crossroads between two major caravan routes. In the 1960s, major irrigation schemes, involving huge revolving sprinklers (2 km across) were started. They rely on the groundwater reserves, and use the fossil energy which is abundant and cheap in Libya.

2.7. NORTHERN CHAD (Figure 2.5)

2.7.a. TIBESTI: GUELTAS OF TOTOUS

1. **Geology and geomorphology of the Tibesti area**

The Tibesti range (c. $10^5 km^2$ surface area) is situated in the South-central Sahara, at about equal distances from the Mediterranean Sea and Lake Chad. It is a mountain triangle with sides c. 400 km, and extending between 19-23°N and 15.5-20°E. The highest peak of the Sahara, the Emi Koussi, is found here (3415 m), but there are more than a dozen peaks of more than 3000 m. The average height of the Tibesti is 2000-2200 m. It is surrounded by low plateaux: the Serir Tibesti (500-800 m) in the North, the deeply dissected Sarra-tableland in the East, and the Plateau of Tchigai, that leads to the erg of Bilma, in the West. In the South-east, the Borkou depression separates the Tibesti from the Ennedi.

Geologically, three main zones can be distinguished. The Precambrian crystalline basement surfaces in the North-west, in a narrow zone of the North-east, and in the South. Palaeozoic rocks cover most of the West, the South and the East, with sandstone the dominant form. Finally, volcanism of Tertiary and Pleistocene age, associated with the alpine orogenetic movement and with a clockwise rotation of the African continent, has produced a thick layer of basalt covering most of the high central region. Postvolcanic activity is still extant; fumaroles, solfatari and mud pots occur near Trou au Natron and Emi Koussi, and over a dozen hot springs are found in Soborom (Tarsi Voon plateau, Central Tibesti). Their temperatures range between 21.5 and 88.5°C. There are more hot springs in the East (Yi Yerra, 850 m, South-east flanc of Emi Koussi, 37°C). Unfortunately, the biology of these springs and of the pools which they supply is totally undocumented.

The climatic fluctuations of the Pleistocene have left numerous traces in Tibesti. Above 1800 m, there is evidence of periglacial phenomena and it has been claimed that, since temperatures down to -10°C may occur, periglacial erosion still continues. Terrace building along the oueds (= Enneris) and pediment formations also indicate a turbulent climatic history. The Pleistocene Mega-Chad, at the time of its maximum extent, reached the foothills of Tibesti and Ennedi.

2. Morphology and hydrology

The core of the massif is a series of plateaux above 2000 m (tarso = plateau) extending from the Tarso Tousside in the west to Tarso Lougo and Tarso Mohi in the east, where an arm extends North to Tarso Emissi, continued in the Dohone mountains, and another one south to the Emi Koussi. A number of volcanic peaks (Emi, E(h)i), many in excess of 3000 m, emerge from these plateaux. Two major rivers (Enneri) further divide the Tibesti into western and eastern zones. The Enneri Yebbigue drains towards the North, and loses itself into a fossil floodplain on the Serir Tibesti, where it is called E. Tanoa. On its course lie a number of major oases and gueltas (e.g. Yebbi Bou, Yebbi Suma, Omchi), as yet totally unexplored biologically. The saddle of Tarso Mohi at c. 1800 m, forms the watershed.

The major Southern Enneri is the Miski. It is augmented from the East by a number of Enneris that drain the western slopes of the Emi Koussi, and in the West by the Enneris Korom and Aouei. It seeps into the depression of Guerede, and supplies a substantial amount of groundwater to the Borkou springs and pools (see below). The gueltas of Oudigei and Totous are on the lower course of the Enneri Aouei. The guelta of Totous lies in a short side-canyon and is well-known for its rich aquatic fauna, but it is one of the very few that has been adequately explored. Numerous other gueltas (Zoure, Ogou, Tougoum...) still await to be prospected. Above 2000 m, the beds of most Enneris contain long strings of gueltas, some connected by running streamlets, others isolated. The permanent gueltas on the Southern flanks of the Tibesti mostly seem to have fish, and some had crocodiles (until 1950, at least), but too little is known about the Northern gueltas and their biota to generalise. A large part of the water that falls on the Tibesti runs off readily and seeps into the groundwater reserves North and South of the massif.

3. Climate

The climate of Tibesti is a desert mountain climate sensu Dubief (1971). There is circumstantial evidence for important regional differences, especially in precipitation, but only few permanent weather stations (Bardai, Trou au Natron) have functioned long enough to provide reliable information. Bardai (1020 m, 21°05'N, 17°00'E) is situated on the Northern flank of Tibesti. It had an annual precipitation of only 12.0 $mm.a^{-1}$ for the period 1957-1968. The value of this figure is, however, relative, as seen from the tremendous inter-annual variations (1966: 60.6 mm; 1962 and 1970: 0.0 mm). Precipitation falls predominantly during early summer, with a peak in May and often in the form of rainstorms (May 1966: 59.9 mm). These are not monsoon rains, but relate to saharo-soudanian depressions (Capot-Rey 1961). For aquatic biota, the precipitation at high altitudes, collecting in the Enneris at lower altitudes, is more significant than that directly received at low altitude sites like Bardai. For example, at Trou au Natron (21°10'N, 16°06'E) at 2250 m, mean annual precipitation is 126 mm, and this figure is probably exceeded by the precipitation on the Emi Koussi. Quezel (1965) thinks that the South flank of this peak receives up to 150 mm per annum. Although there is, here again, a peak in May, secondary maxima occur in March and September (cf. Kaouar oases), the latter doubtlessly of monsoonal origin.

Heckendorff (1973) states that extremely high precipitations are rare in Tibesti. They do, however, occur. Even if at spaced intervals, they provide enough water for springs and well-shaded gueltas to last for many years. Hervouet (1958), for example, noted that at Aożou, North-east of Bardai, 370 mm of rain fell within three days in May 1934. Snow may also occur, although not yearly. Several centimeters fell on Tarsi Voon in 1961-1962.

The average irradiation at Bardai is c. 20,000 $kJm^{-2}d^{-1}$, and increases with altitude. Combined with a low cloudiness (average of 1.5/10 per annum; highest values in April-May and December), this determines high summer temperatures (monthly average of 30.6-30.9°C in June-July, with noon values of 35°C and maxima of 42-44°C, but also diurnal amplitudes of the order of 15-30°C (night values of the order of 10-12°C). The yearly minima fall in December-January (13.3-13.8°C, with an absolute minimum of -5°C, and at Pic Tousside even -11.2°C). The yearly average temperature at Bardai is 23.5°C. Under these conditions, yearly evaporation amounts to c. 6 m, at a mean relative humidity of 25 %. Minima are recorded at noon (10-20%), maxima shortly before sunrise (40-50%). Some extreme low values have been measured at Bardai in reliable circumstances, e.g. 2% on 11 Dec 1966 and on 12 March 1967. Winds blow from the North-east predominantly. In summer, South-eastern and Southern winds, carrying humid equatorial air, increase in importance. In winter, western winds of low intensity also occur.

4. Water chemistry

None of the gueltas seem to have been analysed chemically, but it can be inferred from similar sites in other mountain areas that their ionic content is low.

5. Macrophytes

The Southern Enneris of Tibesti are characterised by a comparatively rich, tropical vegetation, with a considerable degree of endemism (Quézel 1965). A typical association in the vicinity of a guelta is composed of <u>Agrostis stolonifera</u>, <u>Equisetum ramosissimum</u>, <u>Mentha longifolia</u>, <u>Juncus fontanesii</u> and <u>Sonchus tibestii</u>. The last-named of species is endemic to Tibesti. Guelta Totous, situated at less than 600 m, and enclosed between steep cliffs, has little littoral development. On its narrow clayish-sandy edges, growths of <u>Indigofera oblongifolia</u> and <u>Cenchrus ciliarus</u> are found. Various <u>Scirpus</u> and <u>Cyperus</u> species line the guelta directly.

6. Algae

Behre (1950) and Gauthier-Lièvre (1950) studied collections made by Quezel, but very few algae were found in a single sample from Totous valley.

7. Invertebrates

There is no adequate inventory for aquatic insects and mollusca. Only <u>Melanoides tuberculata</u> has been cited from Tibesti, but the malacological fauna of the mountains is certainly richer. Monod (1947, 1950) found <u>Limnocnida tanganyicae</u> in guelta Totous. The pelagial zooplankton of the permanent gueltas is almost certainly poor in species and individuals, because of the vertebrates that abound there. The temporary pools downstream of the main guelta have not been studied.

8. **Vertebrates**

Guelta Totous is famous for its fish fauna which amounts to seven species, the largest number known from any Saharian locality. The following cyprinids occur: Labeo niloticus, Labeo tibestii (possibly a synonym of Labeo annectens), Barbus batesi, B. deserti or macrops, B. anema; the Silurid Clarias gariepinus, and the Cichlid Coptodon zillii. Only three more species are known elsewhere in Tibesti (Barbus apleurogramma, Sarotherodon galilaeus borkuanus, Barilius senegalensis).

9. **Human activity**

Occcasional pastoralism by Tibu tribesmen is the only use that is made of Totous gorge.

2.7.b. MARE DE ZOUI NEAR BARDAI

1. **Geography**

Zoui (21°20'N, 17°05'E) refers to the valley of the Enneri Bardague, called Enneri Zoumeri in its upper reaches. It is the major river West of the Enneri Yebbigue and is cited here as an example of a guelta on the Northern flank of Tibesti. Its climate is as for Bardai.

2. **Macrophytes**

Huge Typha meadows partly overgrow the guelta (Tercafs 1962), but no data on submerged water plants are available.

3. **Algae**: No records.

4. **Invertebrates**

No systematic survey has been performed. Orthetrum ransonneti and Trithemis kirbyi ardens are two dragonfly species that live at this site. The Anostracan Streptocephalus rubricaudatus, a Southern vicariant of S. torvicornis occurs en masse. Associated with it are the Ostracod Heterocypris incongruens, and the cyclopoid copepod Mesocyclops rarus (Van de Velde, 1984).

5. **Vertebrates**: No fish are present. No amphibia have been recorded.

6. **Human activity**

although there is a nearby oasis, there is no specific use of the guelta, other than occasional watering of cattle.

2.7.c. ENNEDI: GUELTAS OF ARCHEI AND BESKERE

1. Geology and morphology

The Ennedi plateau, a 50,000 km^2 sandstone triangle, is situated at the limits of Sahara-Sahel, a little further South than the Air. Its long axis lies E-W and because it is strongly dissected and has a mean altitude of about 1100 m, the Ennedi is often considered a mountain range rather than a plateau. There is a N-S divide at 1100-1300 m. The highest peak, 70 km East of Fada, the main settlement of the area, is estimated at 1450 m (high plateau of Basso). Most of the plateau is naked and desertic, but contrasts sharply with numerous, deep gorges, which are lined with gallery-forest fringed by Acacia-trees. Towards the North, this landscape is bounded by the sandy Mourdi depression which overlies carboniferous limestone and sandstone. It is marshy in places. To the West, the Mourdi depression is continued by the Djourab. In the South (the Mortscha), the crystalline Precambrian basement surfaces. The body of the Ennedi itself is Upper Devonian sandstone to the South of which a steep escarpment runs from the NW to the SE, separating it from lower Devonian sandstone. Even further South and already outside the Ennedi proper, strips of Gothlandian and Ordovician age appear. These, finally, link up with the Precambrian granites.

2. Climate

Like the Air, there is a strong difference in rainfall between North and South, and also between East and West of this massif. Koro-Toro in the Erg Djourab, SW of the Ennedi has 50 mm, but Fada has 80-90 $mm.a^{-1}$, while further North, the Mourdi depression has barely 30 mm. Even less rain falls East of the Ennedi, in the Nile-desert. Altitudinal differences are also strong, and at the level of the N-S divide, it has been claimed that 250 $mm.a^{-1}$ fall. Schiffers (1973) considers this figure an exaggeration. Rainfall is concentrated between June and August, often in tremendous thunderstorms, and erosion on the plateau and in the torrentially flowing oueds is strong. Large year-to-year variations are the rule, and the 1970s were notorious for disastrous droughts. Relative humidity is of the order of 20%, but reaches 70% during the monsoon, when morning dew is not uncommon. Because of this, the summer months are relatively cool, and May is the hottest month of the year (with temperatures of 45-50°C). In December, the coldest month, frost is not unusual (down to -4°C), and dust-haze occurs. Irradiation is of the order of 20,000 $kJ.m^{-2}d^{-1}$, and evaporation is 5-6 $m.a^{-1}$.

3. Hydrology

Of the three superimposed layers of sandstone that comprise most of the Ennedi, the upper one is particularly brittle and subject to erosion. It has been deeply eroded by numerous oueds, with gorges and cliffs up to 100 m deep. Yet, most of this intricate network is of Pleistocene age. The Oued Basso is an example of an extremely narrow, 15 m deep canyon, with a bottom covered by pools and kettle-holes. Around 17°N, the fragmentation of the massif is particularly strong. Two major relict water systems are found here: Archei (16°54'N, 21°46' E), 50 km SE of Fada is a funnel-shaped gorge, 1.5 km deep, and North-oriented from the Southwestern escarpment. Its aquatic environment is composed of six major gueltas, surrounded by stretches of swamp. There are permanent springs at the head of the gorge. 110 km SE of Fada, Beskere (16°30'N, 22°15'E) is a gorge 2 km long penetrating E-W into the escarpment. At its sandy mouth is a dum-palm forest; at its head, 30 springs feed one of the largest gueltas of the Ennedi. These outflow via a permanent channel and form a long series of pools and marshes. The water of the springs is believed to be derived from infiltrated summer rains. Discharges have been measured by Gillet (1957) as 600-700 m^3d^{-1} at Archei, and 1000 m^3d^{-1} at Beskere.

4. Macrophytes

The floors of the Archei and Beskere gorges are covered by thick gallery forest, typical of areas with a yearly precipitation of 600 $mm.a^{-1}$. It is a relict of the Pleistocene wooded savannah that existed here during previous pluvial periods. Gillet (1956, 1957, 1958) cites *Ficus papulifolia* and *Boscia angustifolia* as examples, but *Ficus ingens* (also known from the Southern Air), *Vitex cunerata*, and *Adina microcephala* also fall into this category. The gueltas themselves are surrounded by stands of *Phragmites australis*, *Typha australis*, *T. angustifolia*, associated with cyperaceae and other hygrophytes. There is no inventory of submerged waterplants.

5. Algae

Round (1961) and Compère (1970) examined algal collections from the Ennedi. Collections from Archei contained 95 taxa out of a total of 324. Biogeographically, the Ennedi stood halfway between the Saharian flora and the flora of Lake Chad.

6. Invertebrates

The catalogue of aquatic insects is incomplete. Dragonflies have been studied by Buchholz (1959), and Hemiptera by Dispons (1975). Both authors find a strong predominance of Afrotropical elements, with a Saharian supplement, and among the dragonflies even one Irano-Turanian relict (*Orthetrum ransonneti*, cited sub. *O. kollmannspergeri*). Cladocera and Copepoda were casually collected by Monod and studied by Dussart (1968, 1970), while Monod (1968, 1969) treated the Phyllopoda and Decapoda. *Caridina africana* is the most outstanding find here. Ostracods were studied by Rome (1969). *Limnocnida tanganyicae* was reported by De Miré et al. (1960).

7. Vertebrates

A fragmentary record is available. Four species of fish are recorded: *Barbus macrops* (or *deserti*?), *Labeo tibestii* (or *annectens*?), *Sarotherodon galilaeus borkuanus* and *Coptodon zillii*. This is certainly only a fraction of the true diversity. Many more Silurids, Cyprinodontids, and Cichlids are likely to have survived here. *Xenopus mulleri*, the African clawed toad is common in the gueltas, but the most spectacular vertebrate of Archei and Beskere is undoubtedly the Nile Crocodile, which is still present in sizeable populations. Kollmannsperger (1959) draws attention to the importance of the gueltas for migrating birds, but this is also true for other Saharian gueltas.

The gorges are also a biotope for various mammals who, unlike typical Sahara antelopes (Oryx algazel and Addax nasomaculatus) that never have to drink, need reliable surface water. These not only include groups of baboons (which also occur in the Air, Tibesti and Tagant), but large carnivores such as cheetah, leopard, hyaena and lion.

8. Human activity and management

Although there is evidence for a continuous human presence in and around the gorges since at least 6,000 BP (numerous rock paintings and engravings, representing different styles and ages are found on the cliffs and in shallow caves), there are no permanent settlements here today. Occasional pastoral use is thus the main human activity in the area, and no particular management exists.

2.7.d. THE WATERS OF BORKOU

1. Geography and geology

Borkou is a series of plateaux of decreasing altitude, forming a cascade from N-S between the foot of the eastern Tibesti (Emi Koussi) at c. 600 m asl, and the most Southerly latitude of the Angamma escarpment (250 m). It covers an area of c. 30,000 km^2, and is largely composed of Devonian sandstone. At the latitude of Faya (17°50'N, 19°05'E), the main locality of the area, Tertiary sandstone emerges, and around Faya itself, major deposits of Pleistocene age (sands, clays and diatomites) are found.

2. Climate

Borkou is particularly noted for its strong, dessicating winds which almost invariably blow from the NE. Only during the monsoon is there a limited contribution from the South and SW and there is least wind at this period. Mean annual precipitation is 22.9 mm, more than half of which (13 mm) falls in August alone. There are an average of 3.9 rainy days per annum, and strong differences between years. Totally rainless years are not exceptional, while the record precipitation is 203.4 mm. Depressions of Northern origin may reach the area, but contribute little in terms of real precipitation. Relative humidity is around 20% except during the monsoon, when it increases to 40-50% and damps the diurnal temperature extremes: lower maxima during the day, higher temperatures during the nights. As a consequence, the maximum annual temperatures fall in June (34°C) and decline to 32.7°C in July-August. Minima in December-January are high (21°C), and the freezing point is never reached (absolute monthly minima in January 13.8°C; lowest temperature ever recorded 2.6°C). The highest absolute value recorded is 49.5°C (May). In consequence, the mean annual amplitude (13.7) is modest for a desert environment (compared to e.g. 23.5°C for In Salah). Irradiation and evaporation are as at Ounianga and the Ennedi.

3. Hydrology

Local precipitation is inadequate to provide a supply of water to the numerous pools and springs of Borkou. Capot-Rey (1961) therefore hypothesizes an influx of groundwater derived from the Tibesti, possibly augmented by groundwater from the Erdi plateau. This idea is supported by the fact that most springs in Borkou have fresh water. The saline waters of the Bodele depression in contrast, are derived from Lake Chad. Further, several springs are weakly thermal, an indication of residual volcanic activity. Capot-Rey thinks that some of the Borkou water is therefore juvenile.

Permanent pools and springs are found over a comparatively large area, extending between the Orori, the foot of the Emi Koussi, Tigui, Yarda, Bedo, Yen En Galakka, Faya and other localities. The springs fluctuate in discharge but there is no evidence for a decreasing trend in their number. In fact, oral traditions at Tigui confirm that not one of the local sources has disappeared over the last three generations. At Kirdimi, a new spring even appeared during the present century. All the spring-fed pools are rather shallow and have marshy edges. Salinity in the open basins tends to be high, and salt deposits form along their shores.

4. Water chemistry

Capot-Rey cites unpublished analyses of 14 wells and springs. Four examples, two from the West and two from the East of Borkou depression, are given. Results are expressed as mg l^{-1}.

	SO_4	Cl	Alk. ($CaCO_3$)	Ca	Mg	Na + K
E: Son	48.9	31	205	33.2	5	58.9
E: Mardingai	12.2	15.9	207.5	27.6	4.4	54.5
W: N'Galakka (Chein Marra)	8.1	15.9	85.0	7.0	1.5	7.3
W: Yen	17.7	11.5	50	4	0.6	24.9

There is a trend for the eastern waters to be more mineralised than the western ones, but all are distinctly oligohaline at their origin and therefore, cannot have Chadian origin.

5. Macrophytes

The dum palm is native and abundant in Borkou and is usually found together with _Tamarix brachystylis_ and _T. articulata_. Where agriculture is performed, date palms have also been planted. In wet areas, grasses (_Eragrostis bipinnata_, _Imperata cylindrica_) appear, and in inundated depressions, large meadows of _Typha elephantina_ and _T. australis_ are seen. Endemism is common among the local hydrophytes: _Kosteletzkia borkuana_, _Lotus borkuanus_ are examples. Numerous species are shared only with Tibesti: _Helosciadium muratianum_, _Heleocharis tibestica_, _Epilobium mirei_. Where water fluctuation leaves a dry, saline crust during summer, _Juncus maritimus_, _Scirpus laevigatus_ and _Phragmites communis_ invade the area.

6. Algae

Short lists of species are provided by Gauthier-Lièvre (1950) and Behre (1950) from pools at Kaorchi and Tigui. The pools at Tigui were rich in species, and desmids were particularly well represented. Tropical elements were dominant and most species were typical of freshwater. A single sample from Faya (Largeau) examined by Compère (1967) contained only few species.

7. Invertebrates

Gauthier (1939) reports on the plankton from a pool at En Galakka. Cladocera were dominant (Macrothrix spinosa, Chydorus eurynotus, Alona pulchella), cyclopoid copepods were present but not identified, and the Ostracoda were represented by Cypretta seurati. This list has not been updated since and is clearly incomplete.

Among recent mollusca, Biomphalaria pfeifferi and Bulinus truncatus transmit two forms of human bilharzia, while malaria is also endemic to the area. Gauthier (1939) found numerous water beetles, chironomid larvae and oligochaetes in a plankton sample from En Galakka.

8. Vertebrates

In the Quarternary lake deposits at the foot of the numerous escarpments of Borkou, there are remains of a rich Pleistocene aquatic fauna. Among these is the large predatory fish, Lates niloticus (Daget 1959). There are, however, also recent fish species in some of the waters of Borkou. The cyprinodont Epiplatys senegalensis was reported from a pool at Tigui (Daget 1959). Certainly more fish species await discovery and also Amphibia and reptiles.

9. Human activity and management

The area is inhabited by the Daza, a Southern group of Tibu people. The human population density in the Borkou depression is comparatively high, and many oases are intensely exploited. Natural springs as well as man-made wells are used for irrigating gardens and producing various crops. Date palms have long been introduced to the area, and prosper well.

2.7.e. OUNIANGA

1. Geography and geology

Between the Tibesti in the West, and the plateau islands of Erdi in the east, the Northern edge of the Chad basin is formed of a series of E-W oriented escarpments. They are composed of Nubian sandstone, and contain a number of saline lakes, including the largest ones known from the Sahara. The length of the main escarpment is over 200 km, and the main locality of the area, Ounianga Kebir (c. 19°N, 20°5'E) (the "large Ounianga") (402 m.a.s.l., 235 km NE of Faya) is situated almost exactly in its middle. Four major lakes are found here. Lake Jua (370 ha, max. depth 25 m, alt. 345 m, i.e. 100 m above Lake Chad) is by far the largest one. West of it lie Lakes Uma, Mioji and Forodom. 50 km to the E a second group of lakes occupies Ounianga Serir (c. 18°7'N, 21°E) (the "small Ounianga"). These ten small, parallel-sided lakes (Melekoui, Dierke, Ardiou, Teli, Abrome, Hogou, Diara, Tarem, Tibichei and Bokou) are dominated by Lake Teli (70 ha, max depth 10 m, 360 m asl). Most are small and overgrown by Typha. They are all elongated, with their long axis NE-oriented, in the direction of the prevailing winds.

2. Climate

As in Borkou it is hyperarid and strongly dessicating. The world's record of evaporation (7.8 m) occurs at Ounianga Kebir (Capot-Rey, 1961). Under these conditions, the water of the lakes is evidently hypersaline.

3. Hydrology

The lakes are fed by groundwater that originates in the Eastern Tibesti (Capot-Rey, 1961) and this explains why the local springs are fresh and mildly thermal (30-32°C at Lake Jua). The water of Lake Jua fluctuates with an annual amplitude of c. 1 m. The minimum is reached in August-September, the level starts rising in October, and climbs to a maximum in March-April. There is thus a time lag of c. 1 month between the moment the level starts rising, and the end of the summer rains in Tibesti. Long-term fluctuations have also been noted, and Lake Jua seems to have declined by 60 cm in half a century. During the Pleistocene pluvials, and as recently as 8000 B.P., its level was up to 25 m above the present.

4. Water chemistry

An old analysis on Lake Jua gave the following results:
$NaCl$ 16 $g.l^{-1}$; Na_2CO_3 23.3 $g.l^{-1}$; $NaHCO_3$ 3.7 $g.l^{-1}$;
Na_2SO_4 22.3 $g.l^{-1}$

pH values in the lakes are very high, up to 11.

5. Macrophytes

There are more than 25,000 date palms in the oasis of Ounianga Kebir. The lakes themselves are surrounded by Phragmites australis, mixed with Cyperus laevigatus and Typha australis. Some of the smaller lakes are almost totally overgrown by this association. In the freshwater springs, Lemna spp and floating cyperaceae occur.

6. Algae

Compère (1967) studied algae from different lakes in Ounianga Kebir. In the open water, the colonial cyanobacterium Spirulina geitleri was dominant, often forming thick algal scums. Few species of cyanobacteria and diatoms co-occurred with it in the open water, but in the littoral the community was somewhat more diverse.

In the other lakes, the dominance of Spirulina geitleri was less absolute, and in some a bottom cover of Chara canescens and Ruppia maritima could develop.

7. **Invertebrates**

Except for mosquito larvae and Ephydrid flies, no invertebrates have been cited from the lakes themselves. The freshwater springs are probably richer, but totally undocumented.

8. **Vertebrates**

According to Schiffers (1950), frogs and toads live in the freshwater littoral of Lake Jua. There is, however, no information on their identity. Two fish species have been collected: Haplochromis bimaculatus, and Sarotherodon galiaeus borkuanus. Ounianga Kebir is the type locality for the latter.

9. **Human activity and management**

Besides the traditional oasis cultures, cattle are allowed to graze in the Typha-meadows and natron is exploited at Lake Jua.

2.8. THE EASTERN SAHARA

2.8.a. THE SIWA-DJARABUB (DJAGHBUB) DEPRESSION

1. **Geology**

The western desert (the part of the Sahara between the Nile and the Egyptian-Libyan border) is a huge plateau (mean elevation 500 m a.s.l.) composed of Nubian sandstone in the South and limestone of Eocene and Miocene age in the North. Scattered over this enormous Hamada occur a number of depressions, in which large oases are found. They are situated at the junctions of deposits of different age, uplifted against each other during the Miocene, to form cuestas. The mostly northerly of these is the Djarabub (Libya) - Siwa (Egypt) cuesta with further East the large and deep depression of Qattara. Siwa village is 14 m below sea level, and Qattara even lower at -140 m. They mark the junction of Miocene and Eocene limestone. The Miocene rocks (sloping from 200 m asl at Siwa to 50 m at the Mediterranean coast) consist of an upper layer of solid Marmarican caprock, overlying the much softer Mughra clastics. The origin of this depression (and of the others in the western desert) is fairly complex and still debated in its details. Small depressions were first formed along the cuesta by exudation (chemical dissolution of the caprock by saline water) and eventually joined to form larger and deeper ones. When the free-running layers of clastics were reached, Eolian erosion excavated them rapidly down to the water table, at least in Siwa, where permanent lakes were thus created. The Southern depressions of Kharga, Dakhla, Farafra and Bahariya have limited or no surface water and will not be considered here.

2. Geography and hydrology

The bordering Miocene limestone in the North reaches an elevation of 200 m. It forms a high and generally steep escarpment. The Eocene limestone plateau in the South is at 500 m, but is gently sloping. Escarpments, where present, are generally buried under a sea of sand. The deepest point of Siwa is at -17 m, and the depression is 82 km in length. It has an irregular, elongated shape (25°16'-26°06'E) with a maximum width of 28 km, but in places as narrow as 1.5 km. Its total area is 1088 km^2. On the floor of the depression, a group of minor depressions are occupied by a total of 10-15 lakes. These are the remnants of fewer and larger Pleistocene lakes. Fossil shorelines can be seen at altitudes of -8 to -12 m.

The lake levels fluctuate considerably and some dry up in summer. The most important lakes are:

1. Lake Al-Maraqi : surface area 9 km^2, surface level -17 m
2. Lake Khamsa : surface area 4 km^2. This lake fell dry in 1947, because its water was drained to lake Siwa.
3. Lake Siwa : the largest of all (area 32 km^2), irregularly shaped and with several islands.
4. Lake Al-Zaytun : surface area 16 km^2.

They are saline, but supplied with water from numerous freshwater springs and marshes, which throw up fossil groundwater of Southern origin. Chemical analyses are to be found in Smith (1947).

3. Climate

The climate of Siwa is hyperarid, but not all aspects of it are well documented. Mean annual temperature is 20.5°C. January is the coldest month (mean 10.6°C), and July-August the hottest (mean 29.5°C). Absolute maxima and minima are much more extreme, however, and on the limestone plateau around Siwa winter frosts are fairly common. Mean annual precipitation is only 8 mm. The highest probability for rainfall is during winter, but there are many consecutive rainless years. Potential evaporation is 2.3 $m.a^{-1}$. Local precipitation is therefore negligible compared to evaporation. Relative atmospheric humidity at noon is 15-30%, increasing to 50% at night. Between February and May, hot sand winds (Khamsin) may blow, which reduce humidity to as low as 1%.

4. Algae

Nayal (1935) cites few species specifically from Siwa. Omer-Cooper (1947) reports on algal scums in several salt pools, filamentous green algae in spring outflows, and _Chara_ in waters of various salinity. A much better algological inventory is available for Giarabub (Forti, 1927, 1928, 1933).

5. Invertebrates

One of the peculiarities of Siwa is the occurence of live Foraminifera (Omer-Cooper 1947), a phenomenon paralleled only by the Oued Mya in Algeria. A plankton sample collected in winter 1982 by B. Pejler (pers. comm.) contained large numbers of the rotifer _Hexarthra fennica_. Two species of Cladocera (_Daphnia magna_ and _Simocephalus vetulus_) were recorded from freshwater pools, while Artemia "salina" was restricted to the large saline lakes, and 6 species of Ostracods occurred at various salinities (Harding 1955). Pontopartia salina is believed to be endemic to Siwa. It belongs to a genus otherwise known only from the Bismarck Archipelago but its generic attribution has been challenged by McKenzie (1970s).

Other species of interest are Cypretta murati, known from Chad and Senegal, and Cypridopsis viduella from South Africa and Kenya. Heterocypris salina, Cyprideis littoralis (= torosa) and Eucypris inflata are inhabitants of saline waters. The copepods (Kiefer 1949) were composed of 4 Cyclopoids and 3 Harpacticoids and occurred in oligo- and mesohaline waters only. Apocyclops dengizicus, a mesohaline species also known from Bilma (q.v.), and Afrocyclops gibsoni are the most striking Cyclopoid species. Onychocamptus mohamed and Cletocamptus confluens are widespread in the North African sebkhas, but Nitocra fallaciosa is known only from the Black Sea coast. The Amphipod Gammarus aequicauda is a circum-Mediterannean form (Schaellenberg 1947). The presence of Balanus amphitrite in Birket el Gessabaia, a saline lake, gave rise to speculations about a former connection between Siwa and the Mediterannean Sea (Nilssen-Cantell 1947). There is, however, no geological support for this hypothesis. Introduction by waterbirds is much more likely, especially as the population suffers from heavy mortalities when salinity rises significantly above that of the sea. Among insects, the water beetle Eretes sticticus should be cited, while Crawford (1949) records the gastropods Melanoides tuberculata, Hydrobia musaensis and Pila ovata from the oasis waters.

6. Vertebrates

The euryhaline fish Coptodon zillii and Aphanius dispar occur in the Siwa depression. The former was introduced, and probably destroyed much of the original biocenoses (Omer-Cooper 1947). The latter has strongly melanic populations in some of the oasis waters. As early as 1885, Rohlfs had been struck by an abundance of waterbirds, such as various duck species and ibis.

7. Human activity and management

In contrast to Qattara, Djarabub and Siwa are inhabited, and oasis agriculture is performed with the help of irrigation from natural springs and man-made wells.

2.8.b. JEBEL MARRA: THE DARIBA LAKES

1. Geology

Jebel Marra, situated in the Darfur province of western Sudan, extends SE of the Ennedi and is part of the Nile-Chad divide. Its highest area, a rugged mountain range (12-14°N, 24-25°E) is fully part of the Sahel, and governed by a monsoon climate. Geologically, it pertains to the Precambrian basement, but Tertiary volcanic outbursts were responsible for its rejuvenation. The highest peak reaches 3070 m and isolated volcanoes extend North of the mountain range proper (Djebel Berti and Djebel Meidob). The Malha crater of Dj. Meidob contains a little-known salt lake. Residual volcanic activity has continued throughout the Pleistocene and until the present day. Hammerton (1966) reports on fumaroles and hot springs and Burton & Wickens (1966) think that these may have formed during the 1960s only.

2. Climate

The isohyets at the latitude of Jebel Marra are closely apposed, and a relatively insignificant N-S translation produces a large difference in yearly precipitation. El Fasher (730 m) on the eastern flank of Jebel Marra has a yearly rainfall of 294 mm, with a sharp peak in July-August (138 mm in July; 112 mm in August), but there is virtually no precipitation between October and April. Of even greater importance is the altitudinal effect, which leads to a total rainfall figure of 800 $mm.a^{-1}$ above 2000 m, and even 900-1000 $mm.a^{-1}$ on the high western slopes of the massif. Mean annual temperature at El Fasher is 24.4°C. The minimum occurs in January (19.6°C) and the maximum, in May is c. 29.0°C. The monsoon rains damp the summer temperatures and produce a bimodal temperature curve with a lesser secondary maximum (c. 27°C) in October. At higher altitudes the temperature extremes are wider apart, and winter frosts and hail storms are fairly frequent above 2000 m. The Jebel Marra massif acts as a screen against Northerly winds (Wickens 1976). Potential evaporation is 1.7 $m.a^{-1}$.

3. Geography and morphology of the lakes

Hammerton (1968) mapped the two lakes that occur in the floor (2200 m a.s.l., 5 km diameter) of the caldera of Jebel Marra volcano, the highest peak of which reaches 3024 m. In the NE corner of the floor lies a large but shallow (11.5 m maximum depth) lake (maximum length 2.5 km) while in the SW there is a secondary volcanic cone that contains a smaller (maximum diameter about 1 km) but much deeper (maximum depth 108 m) lake. In addition to direct precipitation, these lakes are fed by both cold and hot springs with temperatures ranging from 65-85°C. Hot springs are particularly abundant West of the shallow lake. Fumaroles are also present, and Hammerton thus concludes that the volcano is dormant, not extinct. Green et al. (1979) measured temperature profiles in the two lakes. Clinograde temperature curves develop in both lakes under calm conditions, but are easily destroyed by winds.

4. Water chemistry

In the shallow lake dissolved oxygen may develop strongly clinograde profiles, with huge supersaturations in the top 50 cm or so (where the algal blooms of Spirulina concentrate), and drop to near zero values at 4 m depth. Anoxic conditions were measured at 6 m and deeper by Green et al. (1979). However, winds quickly mix the water column and redistribute the oxygen. 50% saturation over the entire water column was measured after a windy night. In the deep lake, Hammerton (1970) measured a deoxygenated hypolimnion in 1970, while Green et al. (1979) found a weakly clinograde oxygen curve after a windy period, with only 12% saturation at the surface, and 5% at 30 m.

The chemistry of the two lakes is rather different. The large lake is strongly saline, while the small lake is only mesohaline. Both lakes have high alkalinity and pH values between 9.4 and 9.8.

	total alkalinity $meq.l^{-1}$	Na $mg.l^{-1}$	K $mg.l^{-1}$	Cl $mg.l^{-1}$	cond. $10^{-6}S.cm^{-1}$
small lake	47.5	1,600	95	778	6,000
large lake	147.0	6,200	585	2,580	27,000

5. **Macrophytes**

Cyperus laevigatus grows profusely around the edges of the large lake (Fott & Karim 1973).

6. **Algae**

Fott & Karim (1973) found very high densities (responsible for the narrow fringe of intense primary production on top of the water column, but with a strong self-shading effect at lower levels) of Spirulina geitleri in the shallow lake. Trace amounts of another cyanobacterium, Anabaenopsis arnoldii were found by Green et al. (1979). In the deep lake, pelagic algae were almost non-existent except for some small species of Nitzschia and Melosira (Green et al. 1979). It is, however, possible that the nannoplankton is better developed.

7. **Invertebrates**

Green et al. (1979) found three saline rotifer species in the large lake: Brachionus plicatilis, B. dimidiatus and Hexarthra jenkinae. In the small lake, the same species were present in different proportions and Lecane bulla was also found. Crustacea were present in the small lake only and represented by one cyclopoid copepod Afrocyclops gibsoni. The large lake harboured enormous numbers of the fly Ephydra sp., and the small lake yielded three dragonfly species (Ischnura senegalensis, Hemianax ephippiger, and an Aeschnid larva), the Hemipteran Sphaerodema urinator, the Trichopteran Hydroptila sp., and unidentified chironomid and tabanid larvae (Green et al. 1979). Coleoptera were represented by Hydrophilus senegalensis, Laccobius praecipuus and Potamonectes lynesi the latter apparently endemic to Jebel Marra.

8. **Vertebrates**

No fish are present. No Amphibia have been reported. Green et al. (1979) cite five species of waterbirds: little grebe, sacred ibis, stilt, greenshank and ducks.

9. **Human activity:** Occasional pastoralism.

2.8.c. JEBEL MARRA: THE WADIS

1. Geography

Although the fairly high amount of rain received by Djebel Marra falls in concentrated form, as many as 60 rivers are permanent or have permanent stretches, especially in deep, well protected gorges, where large relict pools may persist indefinitely. Well-known are the Wadi Gallol, W. Korunga, W. Luka, W. Sunni, W. Fik, and W. Mliru. The water of these rivers is presumably fresh, but no analyses are available. Karim (1975) found them to have slightly alkaline pH-values.

2. Macrophytes

In deep gorges, true gallery forests develop. Wickens (1976) discusses three of them in detail, including the Wadi Gallol gorge. The main constituent of the forest, an enclave of equatorial vegetation among dry savannah, is Trema orientalis. Deep, slow-flowing or stagnant pools are bordered by a luxuriant group of trees and shrubs and in the water, similar richness of aquatic plants is also encountered. Citing from Wickens' list: Nymphaea caerulea, N. lotus, N. maculata, Ceratophyllum demersum, Mentha longifolia, Potamogeton nodosus, P. pusillus, P. schweinfurthii, Najas graminea, Lemna minor, L. perpusilla, Pistia stratiotes, Typha domingensis, Juncus spp. (3), Cyperus spp. (12), Eleocharis tibestica. In addition, 33 species of ferns and numerous orchids were found in humid places, where two hepatics also thrive: Grimaldia dichotoma is a species with Mediterranean and Oriental affinities, while Marchantia polymorpha is cosmopolitan.

3. Algae

Karim (1968, 1975) and Starmach (1975) studied algae in Wadi Gallol and other sites on the flanks of Jebel Marra. Diatoms were dominant in the free-floating plankton, but in the littoral and periphyton, filamentous green algae, cyanobacterial colonies, desmids, and flagellates were also abundant. Wickens (1976) found Chara vulgaris to be fairly widespread.

4. Invertebrates

Several groups have been treated, but few comprehensively. Chardez (1974) provided a list of Thecamoebids, a group otherwise almost undocumented from the Sahara-Sahel. Bdelloids and 8 other species of Rotifers are listed by De Ridder (1984), and 7 species of Cladocera were found by Dumont et al. (1984). They include Chydorus sphaericus, Alonella hamata, and Pleuroxus aduncus. The only daphniid recorded was Ceriodaphnia reticulata. Mollusca are imperfectly known (Brown 1980, Van Damme 1984). Bulinus forskalii and B. umbilicatus transmit bilharzia. Lymnaea trunculata, Gyraulus costulatus, Melanoides tuberculata are local.

Happold (1966) studied the dragonflies, and found an almost purely Afrotropical community here, with Pseudagrion hamoni, P. kersteni, Aeshna rileyi as characteristic species. Other aquatic insects are less well known.

5. Vertebrates

Bailey-Watts & Rogers (1970), in a preliminary inventory, list 16 species of fish, including Epiplatys senegalensis, known also from Borkou area. Nile crocodile occurs in pools on the middle Wadi Azum (Wilson 1978) and near El Geneinah.

6. Human activity and management

Jebel Marra has been inhabited since antiquity. Agriculture is practiced by the local Fur tribe who grow, among other crops, wheat. The date of its introduction is unknown, but Lake Chad is a likely source area. The slopes of the mountains are terraced, and used to be cultivated as high as 2750 m, although today cultivation has receded to below 2600 m. There is an interesting seasonal migration of the people between their winter quarters at lower altitude where they produce irrigated crops, and the terraces on the hill slopes, where they grow rain-fed crops during summer (Wickens 1976). In addition to agricultural practices, cattle raising is locally important. All these activities have greatly influenced the natural landscape since prehistoric times. Yet, the greatest alterations, including the extinction of large game, have occurred since the end of the 19th century. The sites with the greatest faunal and floral originality are almost certainly the deep river gorges, often situated between two waterfalls, and hence inaccessible to man.

2.9. THE SOUTHERN RED SEA HILLS

2.9.a. ERKOWIT AREA

1. Geology and morphology of the Red Sea Hills

The hills, flanking the Red Sea on its western side, extend between Suez (Mount Ataca) and the Ethiopian plateau. This longitudinal mountain chain is locally interrupted by faults, and between the chains of peaks thus formed, torrential wadis flow to the sea or to the Nile. They are essentially composed of igneous and metamorphic rock of the Precambrian basement complex. Alluvial infilling has produced a coastal flat of variable width (9-25 km in the Sudan) towards the Red Sea. The mountains themselves have peaks of more than 2000 m (Jebel Erba in the Egyptian-Sudanese border zone is 2220 m high).

2. Climate

The precipitation is a function of latitude. In the Egyptian sector, the area North and South of Quseir is hyperarid and receives less than 5 $mm.a^{-1}$. This amount increases sharply as one approaches Jebel Erba (Elba), and the mountains to the South. The 100 mm isohyet passes just South of Port Sudan and at Gebeit close to Erkowit, 135 $mm.a^{-1}$ are reached. Rains on the eastern slopes of the hills are predominantly winter rains, with a November maximum at Port Sudan. However, at Gebeit, only slightly further South, the influence of the monsoon is also clearly felt, and a peak in precipitation is recorded in August (c. 70 mm). Cloudiness on the mountains is important throughout the year, but peaks in winter. Erkowit (1300 m) is particularly famous for its high incidence of mist that comes in from the sea, and has therefore been called a mist-oasis (Kassas 1956). This is a continuation of the mist zone of the Eritraean coast, where it results in a permanent green belt. The yearly temperature curve is damped, but the mean annual temperature is 25°C at Erkowit with mean minima in December-January (21°C) and a mean maximum of 30°C in summer. Potential evaporation is fairly low for an arid environment: 2-3 $m.a^{-1}$.

3. Hydrology

Close to Erkowit, a number of wadis (locally called Ghor or Khor) have excavated deep gorges, and conserve strings of pools throughout the year. During the wet season (late summer-winter), they are regularly flushed by floods but they reform in January and persist until July. Two of these rivers are Khor Ashat and Khor Amat. The former has cut a deep, funnel-shaped canyon, in which numerous gueltas are connected to each other by a trickle of running water throughout the year. The Khor Amat valley is faulted a few kilometers North of Erkowit. The resulting waterfall feeds a number of deep plunge-pools.

4. Water chemistry

A partial analysis by L.A. Desougi (Khartoum) on samples collected in December 1981 gave the following results:

	total alkalinity $meq.l^{-1}$	K $mg.l^{-1}$	Na $mg.l^{-1}$	Ca $mg.l^{-1}$	Mg $mg.l^{-1}$
K. Amat	3.2	13.8	810	19.12	38.1
K. Ashat	2.2	20.4	260	76.10	92.5

Sodium is comparatively high (probably matched by Cl), and Mg is also above average, but the overall composition is suggestive of an oligohaline water.

5. Macrophytes

No true aquatic macrophytes were seen. However, the vegetation of the area is worthy of comment. Indeed the moisture advected by the frequent mists allows a particular flora to develop, in which terrestrial algae, mosses and ferns (*Asplenium*, *Cheilanthes*, *Adiantum*) develop on a fairly humid soil, produced almost exclusively by *Scirpus steudneri*. Orchids, mushrooms and Abyssinian tree species such as *Aloe abyssinica*, *Euphorbia abyssinica*, the dragontree *Dracaena ombet* and the wild olive tree, *Olea chrysophylla*, are widespread in the area.

6. Algae

Characeae, filamentous green algae and cyanobacterial colonies abound in all the pools. Compère (1984) lists the genera *Spirogyra*, *Oedogonium*, *Cladophora*, *Ulothrix*, *Oscillatoria*, *Lyngbya*, *Cylindrospermum*, *Anabaena*, *Mougeotia*, besides Euglenaceae, green microalgae, Peridinacea, Desmids, and Diatoms. *Nitzschia palea*, *N. obtusa*, *Navicula pupula*, *N.*

subrhynchocephala, *Amphora coffeaeformis*, *Rhopalodia gibberula*, and *Fragilaria ulna* were the most common species among the latter. The algal flora had more affinities with the Middle East than with the Sahara.

7. Invertebrates

Numerous Hemiptera, Coleoptera, Trichoptera and Ephemeroptera occur but have not yet been studied. Dragonflies are few; *Trithemis arteriosa*, *Orthetrum chrysostigma*, *Hemianax ephippiger*, and *Paragomphus genei* have been collected (Dumont & Martens 1984). Four species of Cladocera (*Alona alonopsiformis*, *A. pulchella*, *A. rectangula* and *Ceriodaphnia quadrangula*) were found (Dumont et al. 1984), while Ostracods are represented by 6 species (Martens 1984): *Candonopsis* cf *africana*, *Heterocypris fretensis*, *H. giesbrechtii*, *Cypretta seurati*, *Paracypretta amati* (newly described from Khor Amat in 1984), *Stenocypris major*, and *Plesiocypridopsis newtoni*. De Ridder (1984) lists 20 species of Rotifers. The presence of *Brachionus plicatilis* illustrates the fact that at times the water may become rather saline. Few aquatic molluscs are known. Brown (1980) cites only *Lymnaea natalensis*.

8. Vertebrates

No fish have been recorded, although *Clarias gariepinus* occurs in Khor Baraka, South of Erkowit. A burrowing anuran (unidentified) is common in both Khors, and is active mainly at night.

9. Human activity and management

While the oasis of Erkowit is inhabited, and even has a well-known tourist resort, the Khors themselves are of little interest to the local people. The pools of Khor Ashat are visited by semi-nomads for watering their goat and camel herds. Problems of diarrhoea were noted among the numerous camels roaming through the valley. A high level of certain heavy metals in the water of the pools might be the cause of this.

2.9.b. KHOR ARBAAT

1. Geography and hydrology

Khor Arbaat is a permanent desert river that drains part of the Southern Red Sea Hills towards the sea. It debouches into a triangular alluvial fan, which extends at the mouth of the so-called Arbaat gorge, slightly North of Port Sudan. The upper valley is little explored. The middle sector is said to be more saline than the upper and lower but this needs confirmation. The total length of permanent surface water (either running or consisting of strings of pools) is about 80 km. Rains in winter occasionally cause the river to flow torrentially, but it does not normally reach the Red Sea. Total discharge is, however, far from neglegible and is estimated at $50.10^6 m^3 a^{-1}$.

2. Water chemistry

Water samples analysed by L.A. Desougi in December 1981 from 36°39'E, 19°29'N, were composed as follows:

alkalinity $meq.l^{-1}$	Na $mg.l^{-1}$	K $mg.l^{-1}$	Ca $mg.l^{-1}$	Mg $mg.l^{-1}$
2.6-3.5	160-200	8.5-9.2	8.4-12.8	20.9-26.9

This composition corresponds to an undistinguished fresh water.

3. Macrophytes

Some of the stagnant pools had fringing meadows of *Typha angustifolia*. No submerged macrophytes are on record. The canyon had local growths of cyperacaea in humid places. *Tamarix* sp. and date palms grow on the edges of the valley.

4. Algae

Compère (1984) notes a development of filamentous algae, both in the river bed and on stones, of *Spirogyra*, *Mougeotia*, *Oedogonium*, *Ulothrix*, *Anabaena*, *Cylindrospermum*, *Lyngbya* and *Oscillatoria*. Green and blue-green microalgae and bacteria, flagellates and desmids were also abundant. The most abundant species of diatoms were *Caloneis bacillum*, *C.<clevei*, *C. ventricosa* var *trunculata*, *Cymbella hustedti* f. *stigmata*, *Gomphonema parvulum*, *Navicula cuspidata*, *N. subrhynchocephala*, *Nitzschia elegantula*, *N. hustedtiana*, *N. microcephala*, *N. tryplionella*.

5. Invertebrates

De Ridder (1984) found 10 species of rotifers, while Dumont et al. (1984) report the Cladocera *Alona rectangula*, *A.<pulchella*, *Macrothrix spinosa*. Martens (1984) identified 8 ostracod species: 4 of these belonged to *Hemicypris* and in addition *Limnocythere stationis* and *Ilyocypris gibba* were found. Dragonflies (Dumont & Martens 1984) are noteworthy for the occurrence of two gomphids (*Paragomphus genei* and *P. sinaiticus*). The only zygopteran present was *Ischnura evansi*, a species with a predominantly Irano-Turanian range. Other insect groups remain undocumented.

6. Vertebrates

The cyprinodont *Aphanius dispar* occurs in tremendous densities throughout the Arbaat valley (Sandon 1950; Dumont 1981, pers. observ.). This euryhaline species is also found among coral reefs in the Red Sea, and is a landlocked relict of former higher levels of the oued. Other fish species have not been observed. A remarkable reptilian is the water turtle *Pelomedusa subrufa*, which has also been seen in Wadi Amur on the western side of the divide. Wild asses, gazelles, nubian ibex, and leopard still live in and around the Arbaat catchment.

7. Human activity and management

Stray stands of date palm are scattered over the valley in small oases. Some gardens are irrigated. The main function of Khor Arbaat is, however, to supply drinking water to the city of Port Sudan. A pumping station has been erected for this purpose at the mouth of Arbaat gorge. It pumps up the water slightly beyond the point where it starts seeping into the sands of the delta, and conveys it to the town.