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SCIENCE DIRECT
Building and Environment 39 (2004) 719–732
BUILDING AND ENVIRONMENT
www.elsevier.com/locate/buildenv

# Decline of urban ecosystem of Mzab valley

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Received 24 April 2003; received in revised form 28 June 2003; accepted 1 December 2003

**Abstract**

Mzab settlements are a group of five towns implanted along the valley of Mzab in the south of Algeria. They were developed in response to site and climatic constraints and adjusted well to rational urbanization for many centuries. Traditional ways of adaptation to these conditions were based on ecosystem balance management and on efficient exploitation of natural resources. The sites are selected to assist defense, to benefit from summer breezes and to promote natural drainage, whilst providing shelter from the sun and adapting generally to severe local climate. Rapid growth and structural changes in the local economy, coupled with accelerated urbanization generated a variety of significant environmental problems such as perturbation of environmental hydrology, pollution and thermal discomfort. The impact of these problems upon the well-being of the inhabitants have become a major preoccupation. The most important aspect of Mzab structural characteristics is the transition from traditional into a modern structure and the observation of a fast transformation process from the economic sectors. A great deal has been written about history, architectural and town planning principles for Mzab settlements in Bouchair and Dupagne (Building Environ. (2003), to be published) [1]. However, much remains to be dealt with and elucidated concerning the ecosystem and ecological balance of the Mzab area. In this paper, we try to demonstrate the role of traditional practices for maintaining ecosystem balance and protecting natural environment in the Mzab valley. Also, discussed and analyzed are the degradation of traditional practices of environmental control and its implications upon the ecosystem balance and the thermal comfort for the inhabitants.


*Keywords:* Mzab settlements; Urban ecosystem; Microenvironment

## 1. Introduction

Mzab settlements are a group of five towns (El Atteuf, Bounoura, Beni-Izgen, Melika and Ghardaia) divided into three administrative units or communes, which by their position along the Mzab valley form a coherent geographical unity. In the last few decades, the urbanization of the valley has exacerbated and has developed a number of environmental problems from which the most important are: perturbation of the environment hydrology, pollution and the urban heat island. The new urban growth, which takes place on the valley blanket, caused the perturbation of the microenvironment by the new material used, by the industrial activities, which have developed, and by the regression of vegetation. This has direct impact upon the public health, and thermal discomfort and on the energy consumption in buildings. Traditional practices, which developed in the past to meet urbanization and climatic requirements, have been in unprecedented decline in the last few decades. The multiplication of mineral surfaces: such as bitumen roads and paved areas, new urban structures and human activities has considerably developed and these have reduced the capacity of the urban environment to face the new environmental problems. Especially, in an area which is characterized with very harsh climatic conditions. Its atmosphere is very dry and this gives a significant potential of evaporation. The rainfalls are very low and irregular giving a mean annual value of 60 mm. The precipitation fluctuates between a maximum of 120 mm and a minimum of 20 mm. Rainfall could only occur any time between October and February. The number of days of rainfall per year do not exceed 15 days. Solar radiation and temperature are high in summer time and relatively low in winter. The mean temperature in July is 35°C with a maximum of 45°C and a minimum of 27°C. In January, the mean temperature of the ambient air is about 10°C with a maximum of 20°C and a minimum of 3°C. In winter, the prevailing winds come from the N-W and they are cool and humid. The mean wind speed in January is 12 km/h with a maximum of 29 km/h. In summer,

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doi:10.1016/j.buildenv.2003.12.001

the prevailing winds come from east and they are hot and dry. The mean wind speed in July is 13 km/h with a maximum of 29 km/h [2].

The fundamental elements for the establishment of the human ecosystem of Mzab are: water, food and shelter. Food may be transported more easily than water and shelter. For Mzab, inadequate local production at first led to trade with the surrounding nomadic population. Eventually, this developed into a network of commercial exchange with the North of Algeria. Water supply was mainly based upon occasional rainfalls during winter and underground water of the valley. Shelter is built in response to a harsh local climate to offer comfortable living conditions both inside and outside the home. The site is selected with an eye to environmental protection, especially for security, promotion of natural drainage and to benefit from summer breezes. Buildings are built compactly from locally available materials, such as plaster, mud, stones and palm branches. Streets are narrow, irregular and generally covered to avoid direct exposure to sunrays, glare and sandstorms. Each house has a courtyard, which serves both family life and thermal control. Outside spaces such as roofs are designed to be used for sleeping at night. Palm groves modify the local microclimate and provide protection from sandstorms and dust. Expansion of traditional settlements responded well to the slow increase of population and planning and design relied on traditional skills and knowledge. The homogeneity of the site, the harmonic development of the settlements and the ecosystem balance are thus preserved. But in the last five decades, the discovery of oil and gas fields, artesian wells, the construction of a traffic infrastructure, the introduction of new industry and the implementation of new administrative units have greatly affected the regional economy. The population has increased significantly; largely due to migration from other regions. The urbanization of the valley has increased, and has resulted in the rise of new building and the decline of traditional urban forms and vernacular architectural values.

The Mzab ecosystem is undergoing rapid change and is being challenged everywhere, at an unprecedented rate and on a scale which raises grave concerns for the environment. This paper is a complementary work to the first one presented in [1]. It is largely based upon field survey and site observation, through which it is hoped to achieve better understanding of the design aspects and the peculiarities of traditional Mzab practices in relation to the natural environment. Also, discussed are the impact of the modern urbanization and social activities and the consequent degradation of the microenvironment in recent decades. Strategies and solutions to meet these challenges and to reduce or repair the damages are proposed.

## 2. Traditional practices for ecosystem and microenvironment control in the valley of Mzab

For their health and well-being, Mzab inhabitants have put great effort into maintaining the ecological balance and the sustainability of their ecosystem, which embraces both the animate and inanimate components of their environment. The principal ways by which Mzab people manage their ecosystem are: control of the community growth, climatic-responsive shelters, water resources and supply management, plantation and use of low waste methods.

### *2.1. Control of the community growth*

Population was once kept in balance by variations in the death rate, or by emigration to establish new settlements. This, in fact, is how the five settlements of the Mzab were founded. A community which has reached the point of culmination and which has experienced no form of release is likely to settle into a condition of stagnation. Its natural surplus of population is forced to emigrate. This is justified by the fact that the Mzab settlements were built successively, one after the other. El-Atteuf built in 1012 AD, Bounoura built in 1046 AD, Ghardaia in 1053 AD, Melika in 1124 AD and Beni-Izgen in 1347 AD. Three centuries later, away from the Mzab valley, Guerara was built in 1630 AD and Beriane was built in 1679 AD. In 1879 AD, Coyne [3] estimated the population of El-Atteuf to be 2500 inhabitants, Bounoura 1500 inhabitants, Melika 1200 inhabitants, Beni-Izgen 5500 inhabitants and Ghardaia 11 000 inhabitants.

### *2.2. Climatic-responsive shelters*

Mzab inhabitants, as most people of hot climates, have learned from long experience various ways of maintaining comfort inside dwellings. Much has been done to reduce the discomfort by the use of courtyards, use of local materials, shading from direct sunlight, and by adaptation to climatic patterns.

#### *2.2.1. The use of topography*

Mzab could have known from their long experience in the desert that topography can modify microclimate. Basin valleys reflect and concentrate the solar radiation while cooling air movement is impeded. Mzab settlements are built either on slope of the valley or on top of hills. El-Atteuf, Bounoura and Beni-Izgen are built on slopes of the valley. Melika is built on top of a piton. Ghardaia, which is surrounded by the valley slopes, is built on top of a hill. Fig. 1 shows diagrams of the way the topography is exploited to deal with environmental problems.

#### *2.2.2. Minimization of surface exposure to direct sun*

Surface exposure to direct sun and heat gain through building surfaces is reduced by:

- Compact cellular layout with unexposed common walls in Ksurs. Fig. 2 shows the lay out plan of Ghardaia as a typical example.
- Blind external walls to reduce radiation through windows.

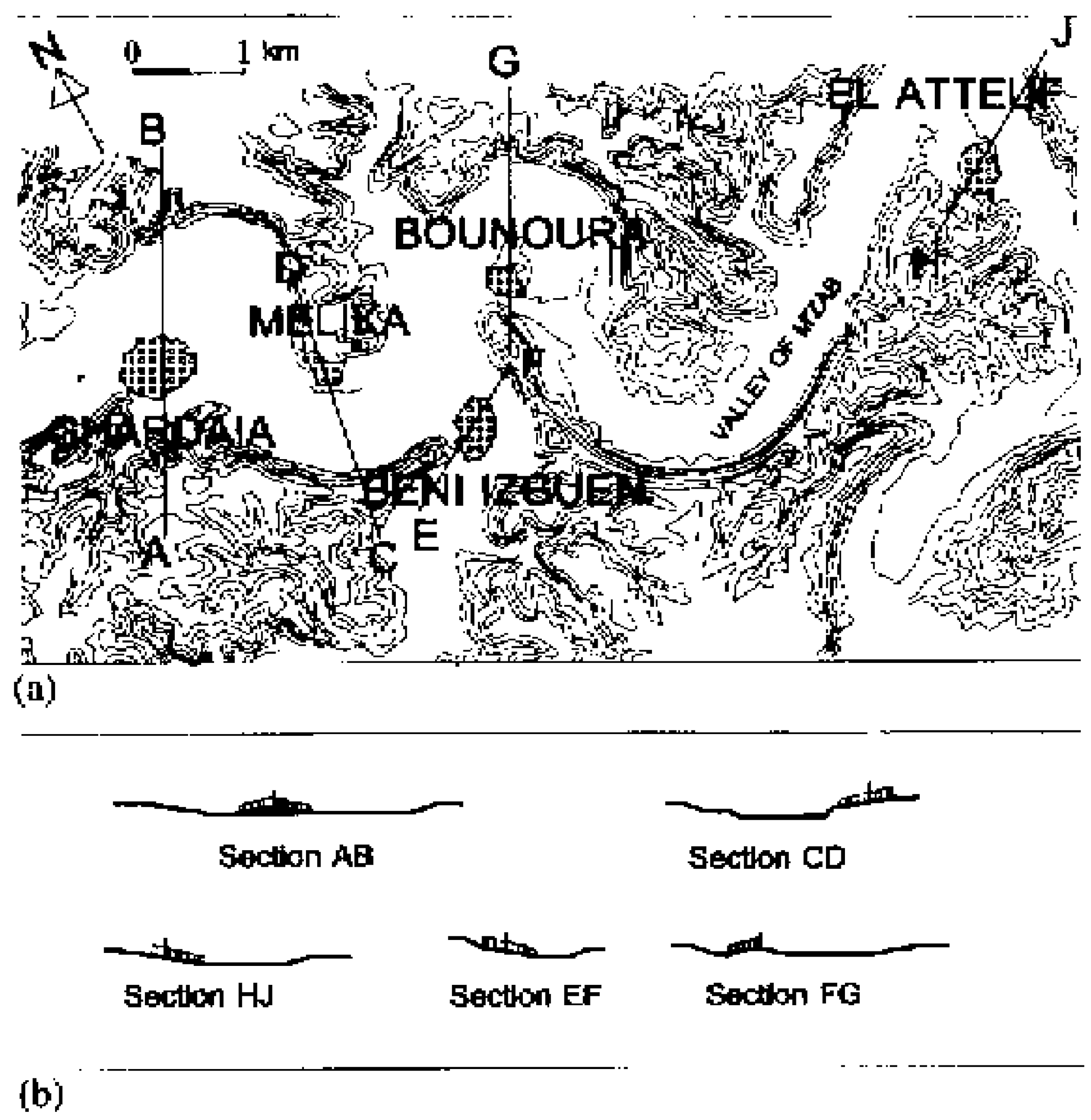



Fig. 1. Diagrams showing how the topography of the site is exploited to well adapt with the natural environment (a—site plan, b—sections through the Ksurs and the sites).

Fig. 2. Mass plan of Ghardaia as a typical compact cellular lay out.

### 2.2.3. *Use of local materials*

Shelter is an essential factor in the stability of Mzab society, so that much importance is given to its durability. This has been achieved in the methods of construction and building material used. The settlements are built of locally available materials like stone, wood, lime, clay or mud, in harmony with the environment. Random stone walling in lime mortar is used, the lime or "*timchemt*" being extracted from calcareous rocks (gray, red or white color) abundantly found at a depth of about 0.3 m on the plateau which dominate the valleys of Mzab. The lime extracted is fired and dried in small traditional ovens. It dries quickly and has high resistance and cohesion. Wood is cut from palm trees and used in beams, windows and doors.

Fig. 3. Photograph showing a typical ceiling constructed with palm branches joined together and arranged between timber bearers.

The building walls are 1 m thick at the base and reduce to about 0.2 m at the roof level, and may be faced or rendered with lime plaster. They are laid directly upon rocky soil. Large random-sized blocks in lime mortar are used in foundations and walls, which carry floors and flat roofs. Thick walls and roofs work as insulators and reservoirs of heat during the day. Heavy buildings provide relatively comfortable internal spaces during the day and reduce fluctuation of internal temperature. Unfortunately, in the evening much of the stored heat is admitted to the inside of the buildings causing discomfort. In summer nights, the temperature inside buildings reaches 30–40°C. This is why the inhabitants during this season migrate to the palm groves. But for inhabitants who have no homes in the gardens use the basements to perform evening activities and at night they use the roofs for sleeping to catch breezes and radiative coolness of the sky.

Floors are constructed with palm branches joined together and arranged between timber bearers. With such materials, thermal and acoustic insulation is provided. Fig. 3 shows a typical ceiling constructed from palm branches and timber beams. The timber bearers are usually about 2 m long and separated from each other by 0.3–0.4 m. They span between plates on the load-bearing walls. Arches and semicircular stone vaults are also used, supporting stone floors bound with lime mortar with a top layer of compact mud about 0.2 m thick to improve thermal insulation.

### 2.2.4. *Use of high-albedo surfaces for the building envelope*

In order to reduce surface absorptivity to solar radiation and can therefore greatly reduce building cooling loads, Mzab inhabitants use high-albedo surfaces and materials that are more reflective of the solar radiation. The roofs, revetment and walls are covered with lime plaster and whitewashed or painted a light color, light blue or yellow.

### 2.2.5. *Adaptation to climatic patterns*

In addition to the role of the courtyard in providing comfort, daily activities are adapted in response to climatic patterns:

- Within the dwelling, the family use the roof of the house for sleeping in the open air in the summer nights. The roof is usually subdivided with partitions to provide separate spaces for children, parents and guests. Parapet walls, which also enclose the roof area, are built high above the roof for visual protection of the family and to provide shade.
- Outside the dwelling, inhabitants move from Ksurs to city gardens during summer, and vice versa during winter. This movement has been reduced significantly due to the housing shortage.
- Commercial, cultural and other social activities take place in the morning and late evening, during which time the outside conditions are comfortable.

### 2.2.6. *The courtyard*

It is also used for thermal regulation. It allows air movement within the dwelling. This caused by the temperature difference between cool air within the shady streets, and hot air within the courtyard. Hot air within the courtyard moves upwards, from first floor ground through the top opening, *Shebek*, to other upper floors into the external atmosphere, and is replaced by cooler outside air. The position of the courtyard within the dwelling makes it much quieter than the alleyways. It is less open in the lower than in the upper levels, and is divided into two. One part is open upwards for light and ventilation, and the other is a covered walk or porch. The porch, which is used for various family activities, is a balcony which partially or totally surrounds it in order to minimize direct solar gain. Fig. 4 shows a schematic diagram showing how courtyard functions to maintain thermal regulation in a typical Mzab dwelling.

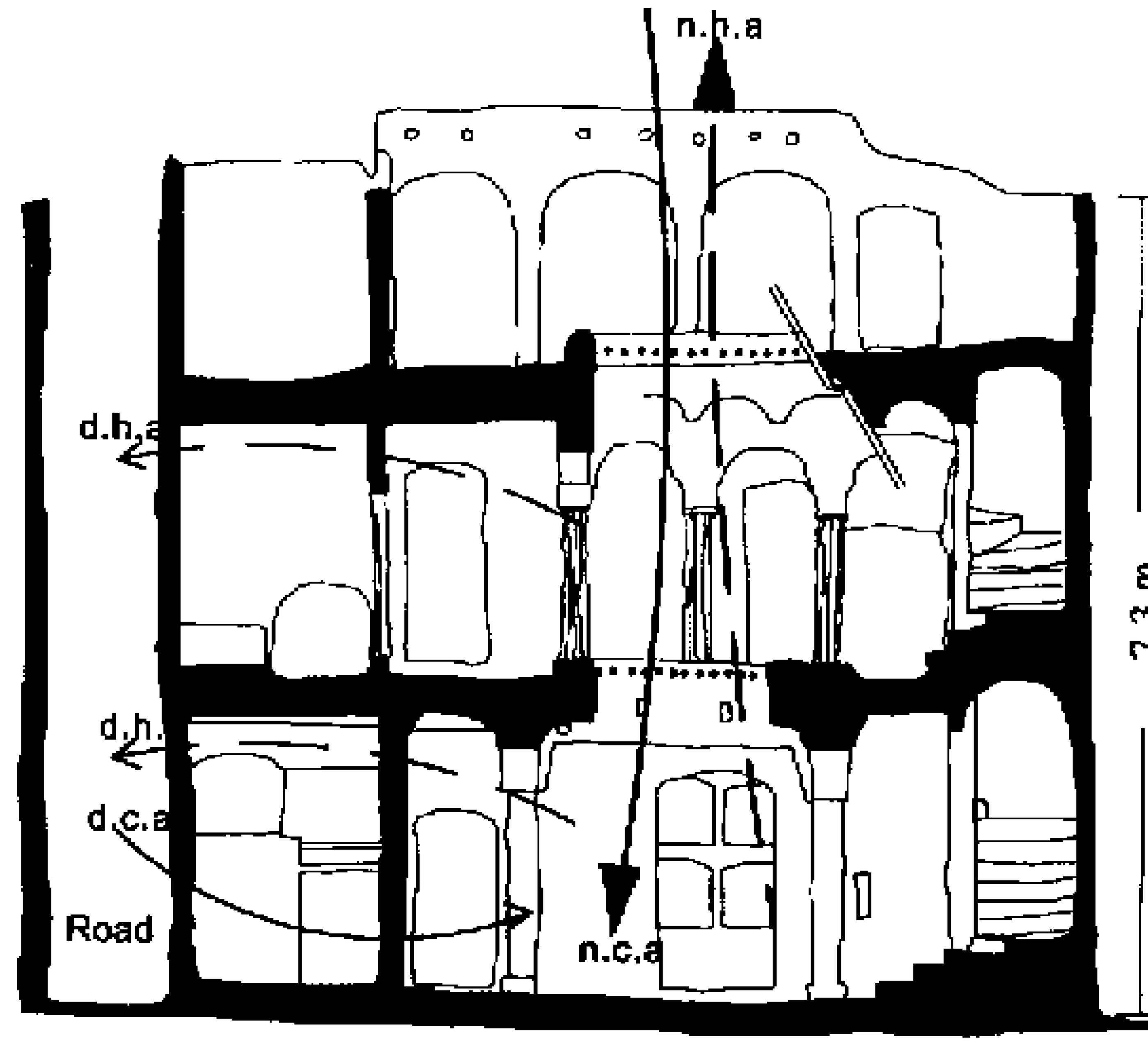



Fig. 4. Schematic diagram showing how a courtyard is used to regulate thermal environment of a typical Mzab dwelling (key: n = night, c = cool, h = hot, a = air, d = day).

## 2.3. *Water resources and supply management*

Water has been a major preoccupation of the Mzab community. It has played a crucial role in nurturing the vegetation, in social life and religion. Drinking, washing and bathing were, of course, important factors in the daily battle against heat and dust.

Water resources in Mzab are divided into two kinds:

- *Surface water*: which flows in wadis and springs which depends on rainfall and it contributes partly to groundwater.
- *Groundwater*: including surface groundwater, and renewable groundwater resources which depends on the annual rainfall. It is situated at a depth of 10–50 m.
- *Deep groundwater* (*nonrenewable*): It is the water which is stored in aquifers, throughout old times inside earth and it is found under renewable groundwater aquifers at a depth of 400–500 m. The volume of its water depends on the thickness and storage capacity of the ground layer in which it is found, and on the horizontal layout of the layer.

Facing water scarcity, Mzab community arranged the valley to exploit every available drop of water, as follows:

### 2.3.1. *Water for domestic use*

Wells were dug throughout the valley plateau, in the Ksurs and in City gardens to supply drinking water. The depth of the surface groundwater levels vary, generally, from 10 to 50 m (less deep as we go down the valley). The wells are lined with stones and they are capped with a traditional mechanism—two pillars to which is fixed a horizontal bar supporting a metal pulley. In the courtyard of Melika mosque, exists the deepest well in Mzab (about 55 m deep) and is the only one there.

Unfortunately, in the last few decades, these wells were abandoned and were replaced by a modern net of water supply managed by public authorities. The water is driven from aquifer groundwater at a depth of 500 m. The deep ground table is a large reservoir under the Mzab valley blanket. This is linked to reservoirs at high lands around the valley before it arrives to population. These reservoirs occupy positions which have a negative impact upon the harmony of the environment and dominate the ksurs and watch towers

Fig. 5. Surface water net supplying the valley and how it is captured and exploited.

which have been built by the principle to be the dominant elements. One of the greatest problem which faces the environment is that the deep groundwater level is in continual reduction in quantity of water and 1 day will be insufficient, especially with the degradation of traditional ways of collecting surface waters and the supply of superficial wells, and further more the occupation of the old sites (dumps, wads and wells) for this purpose by urbanization.

### 2.3.2. *Water for irrigation*

Various systems for capturing, controlling and distributing water for irrigation have been developed, including:

- Rainwater falling directly upon the valley plateau or on top of hills is channeled downward to be diverted for irrigation with the surplus turned back to be stored in dams or to the valley (Fig. 5).
- In order to reduce soil erosion due to runoff on bare land, and to feed the underground water table during occasional rainy periods, water movement in the valley is controlled by constructing stone walls or embankments along the valley. These walls are built solidly of stone with lime or cement (Fig. 6). Partial high pressure of the water is weakened by the construction of the breakers ⟨⟨*Essembad*⟩⟩. Fig. 7 shows Essembad to break excessive water pressure for Ghardaia garden city.
- In general, erosion is the source of sediment that fills streams, pollutes water, kills aquatic life, and shortens the useful life of dams and reservoirs. These walls reduce the pressure of floods and avoid destruction. They also capture and delay water loss downstream from two or three days, to a month. Excess flow is diverted to replenish wells. Fig. 8 shows water diverters.
- The irrigation of palm groves is by underground open-ended tunnels. Distribution is by gravity only. The tunnels are covered with flat stones and extend for hundreds of meters and lined with locally prepared gypsum or "Timchemt". They are generally grouped together at inlets (Fig. 9) and separate towards outlets (Fig. 10). The sections of tunnels change towards the outlets, and there

Fig. 6. Photograph showing walls across the valley to collect water, reduce floods pressure and avoid destruction.

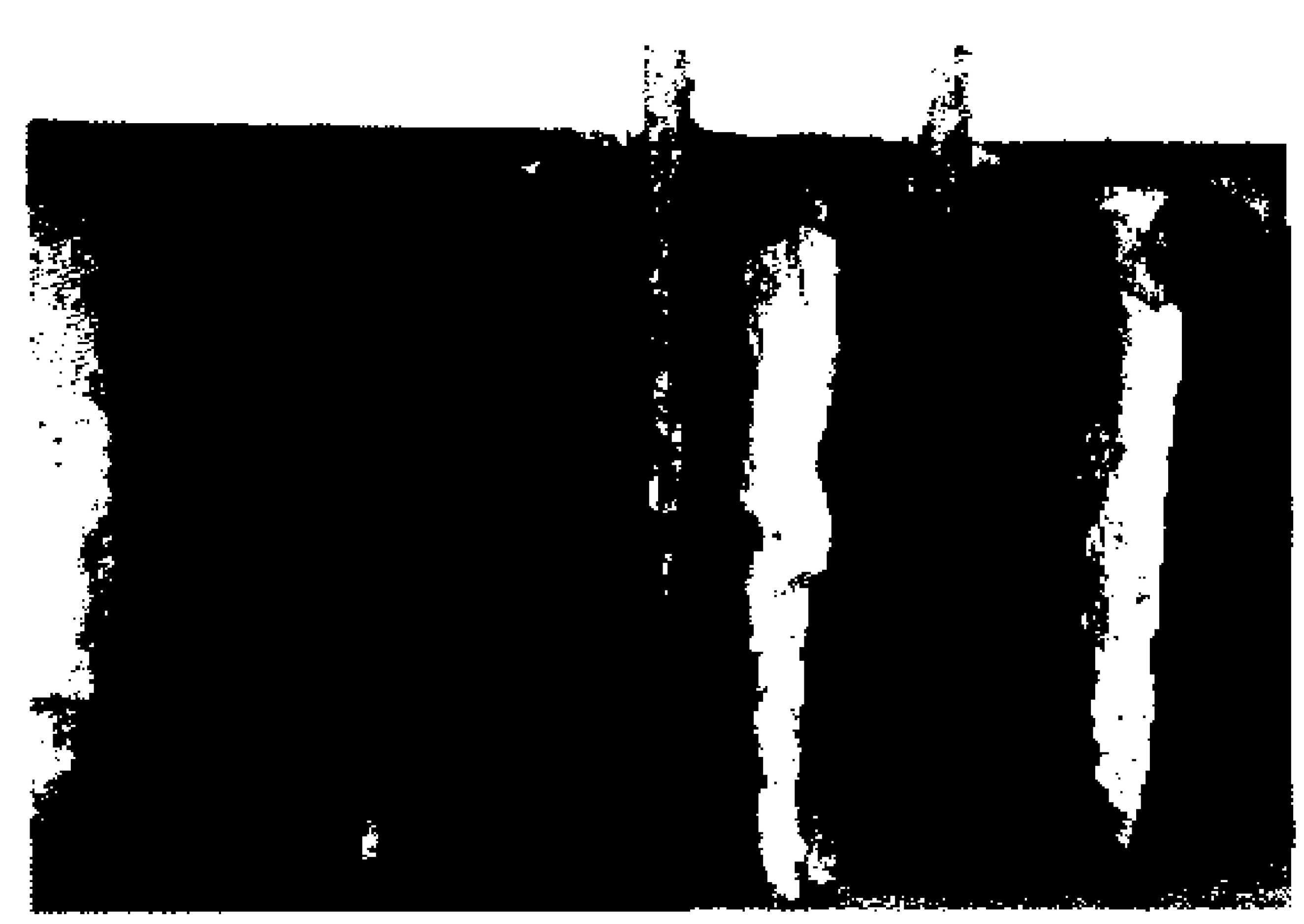


Fig. 7. Photograph showing water distribution system (*Essembad*) to break excessive water pressure for Ghardaia garden city at (c) position in Fig. 14.

Fig. 8. Photograph showing typical water surplus deviator from canal (a) into dam (b) (see Fig. 14).


Fig. 9. Photograph showing the inlet of channels at (c) position in Fig. 14.

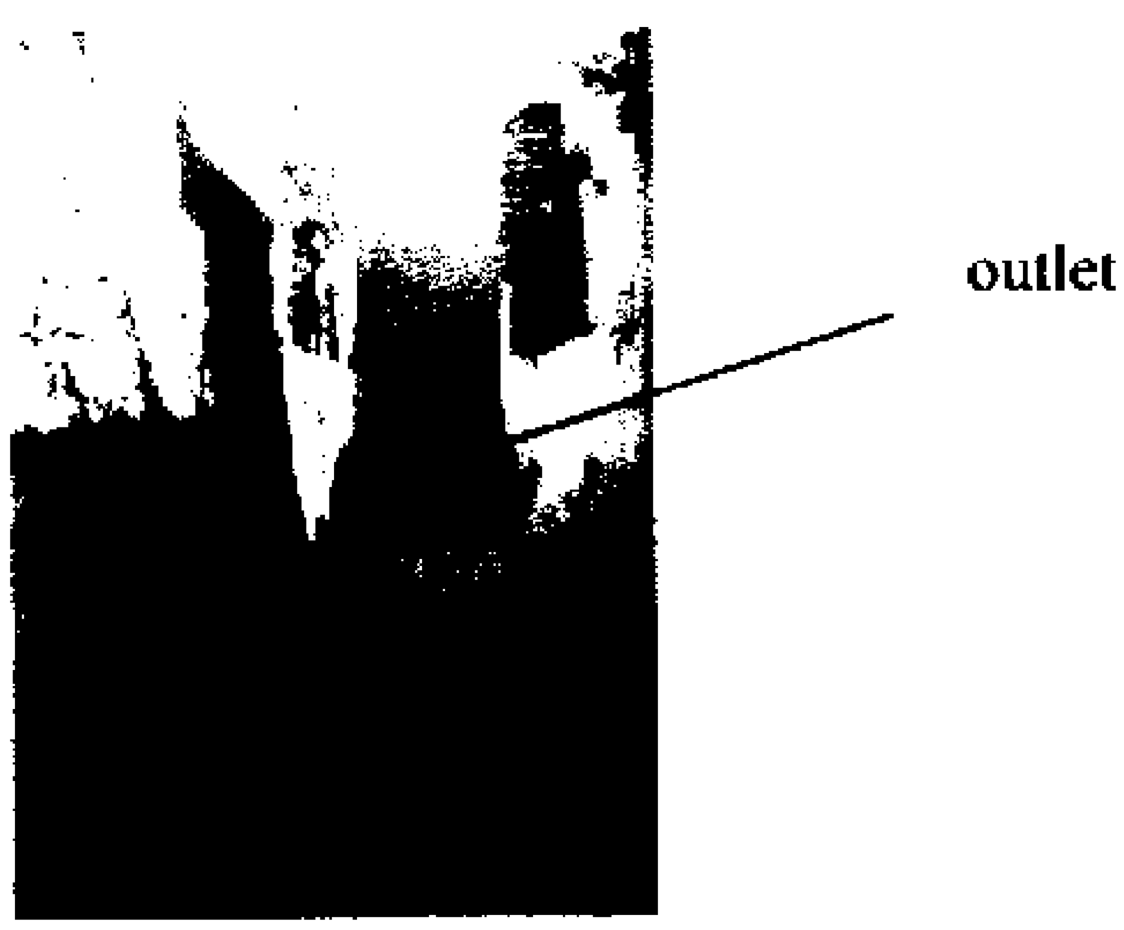



Fig. 10. Photograph showing the outlet of an underground tunnel at (c) position in Fig. 14.

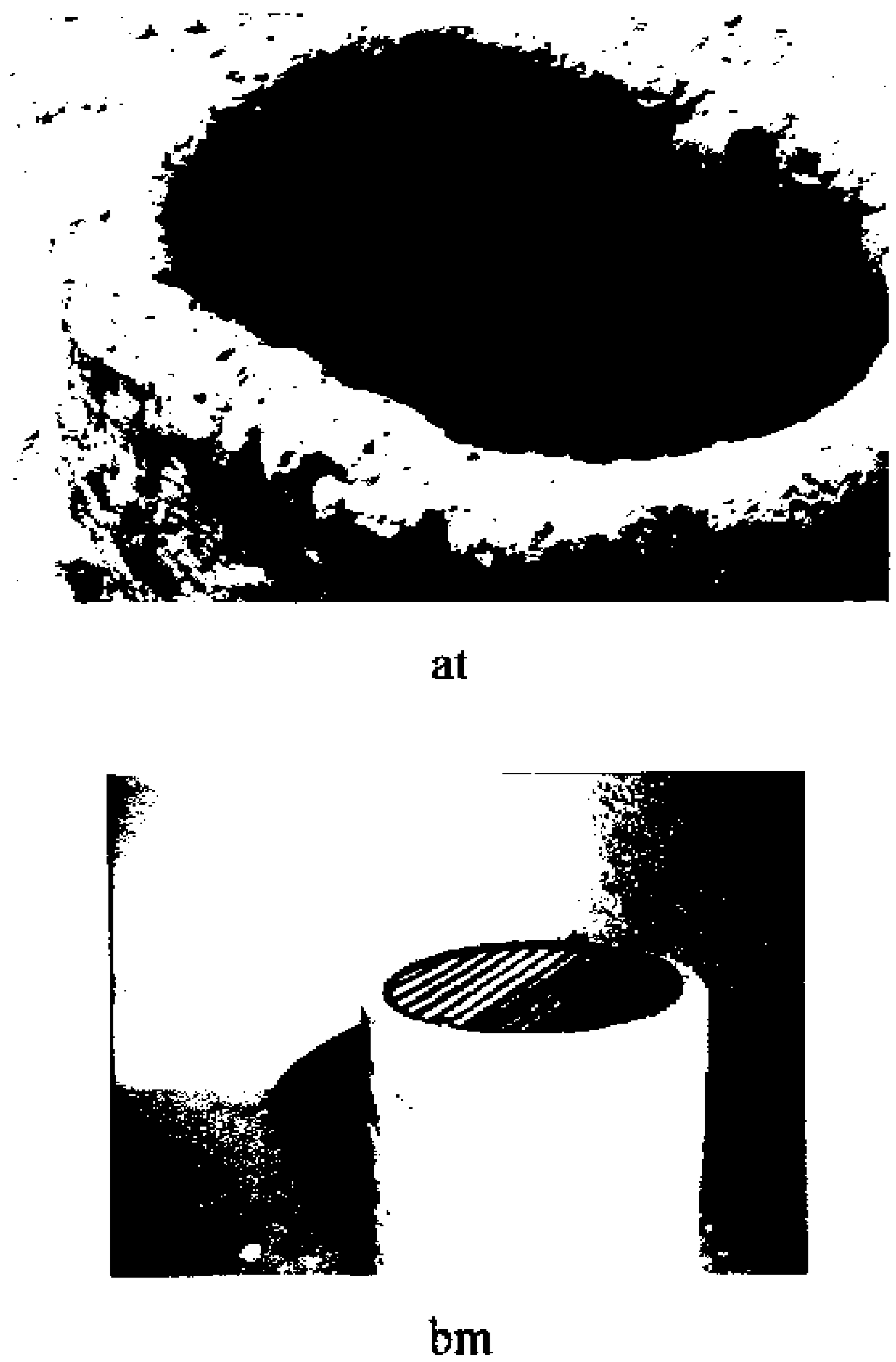



Fig. 11. Photograph showing sumps to assist ventilation and maintenance at (d) position in Fig. 14: (at—Traditional, bm—Modern).


Fig. 12. Photograph showing typical alley way used for water drainage and pedestrians at the same time in gardens at (f) and (g) position in Fig. 14: on the left wall at the bottom we can see water inlets leading into gardens (*Tissembet*).

are sumps at intervals to assist ventilation and maintenance (Fig. 11). Sump intervals, shape and dimensions are determined by the rule of thumb. Each tunnel issues into a district of city gardens where the alleyways are arranged in inclined channels (Fig. 12). To allow better drainage, some openings are arranged on the lower side of the wall of each garden, sized in relation to its area, the number of palm trees, so that each receives the quantity of water required. Fig. 13 is a site plan showing how rainwater is captured and driven to gardens and dams. Fig. 14 is a typical schematic diagram showing how rainwater is channeled and distributed to irrigate Ghardaia gardens.

### 2.4. Vegetation

Mzab communities plant palm trees for two reasons: to produce dates and modify the microclimatic. Unlike Ksurs, which are compact tissues having no trees in city gardens buildings are scattered. Palm trees are the most suitable plants for desert conditions. The trees shade the ground surface causing a reduction in the environmental temperature, with the advantage of cooling by evapotranspiration through the leaves. The trees reduce as well the evaporation from ground surfaces and avoid erosion. They are also a source of wood for traditional building. Fig. 15 shows city gardens of Beni-Izgen and Ghardaia as typical examples.

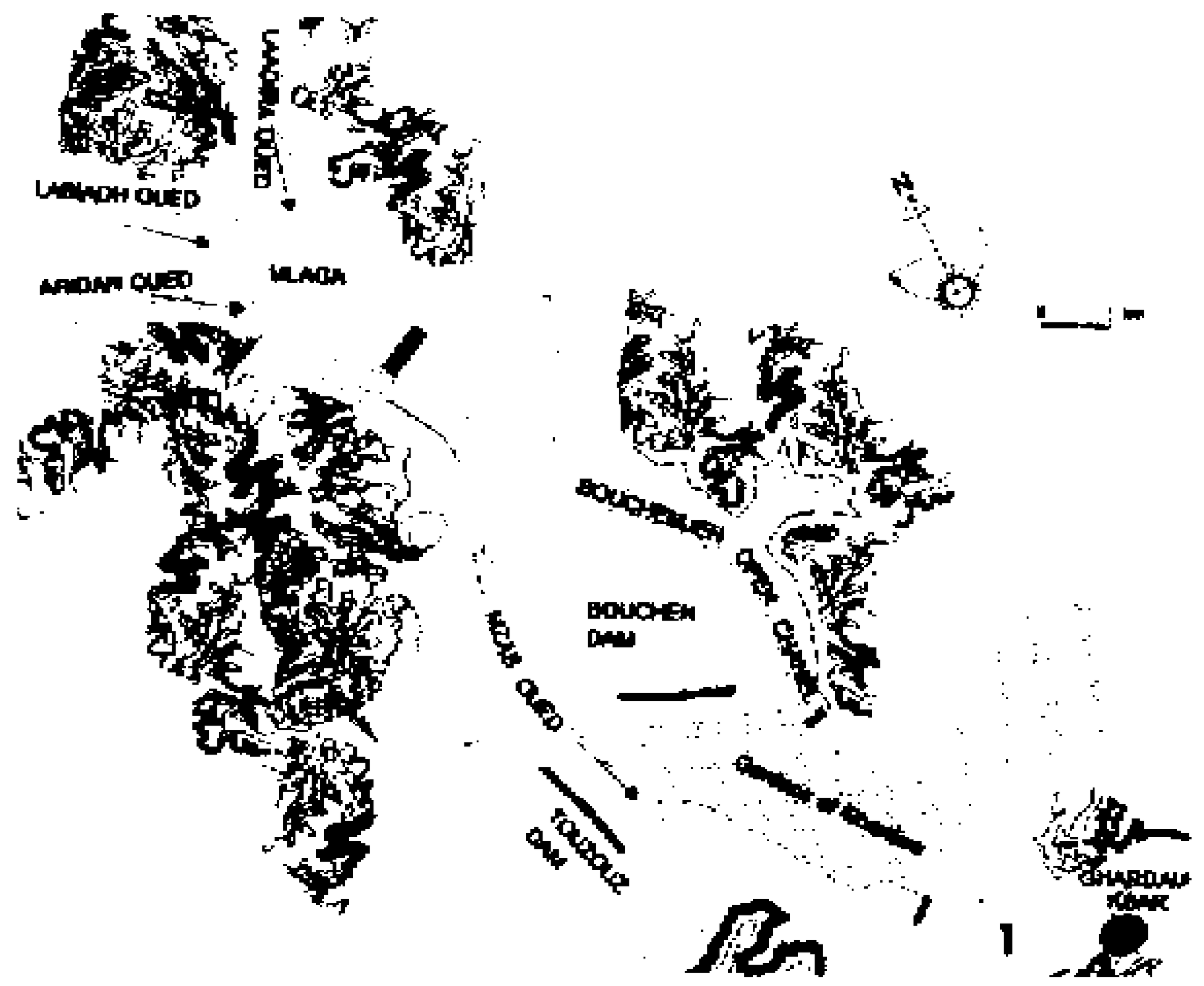


Fig. 13. Site plan showing how rain water is captured and driven to Ghardaia gardens and Bouchen dam.

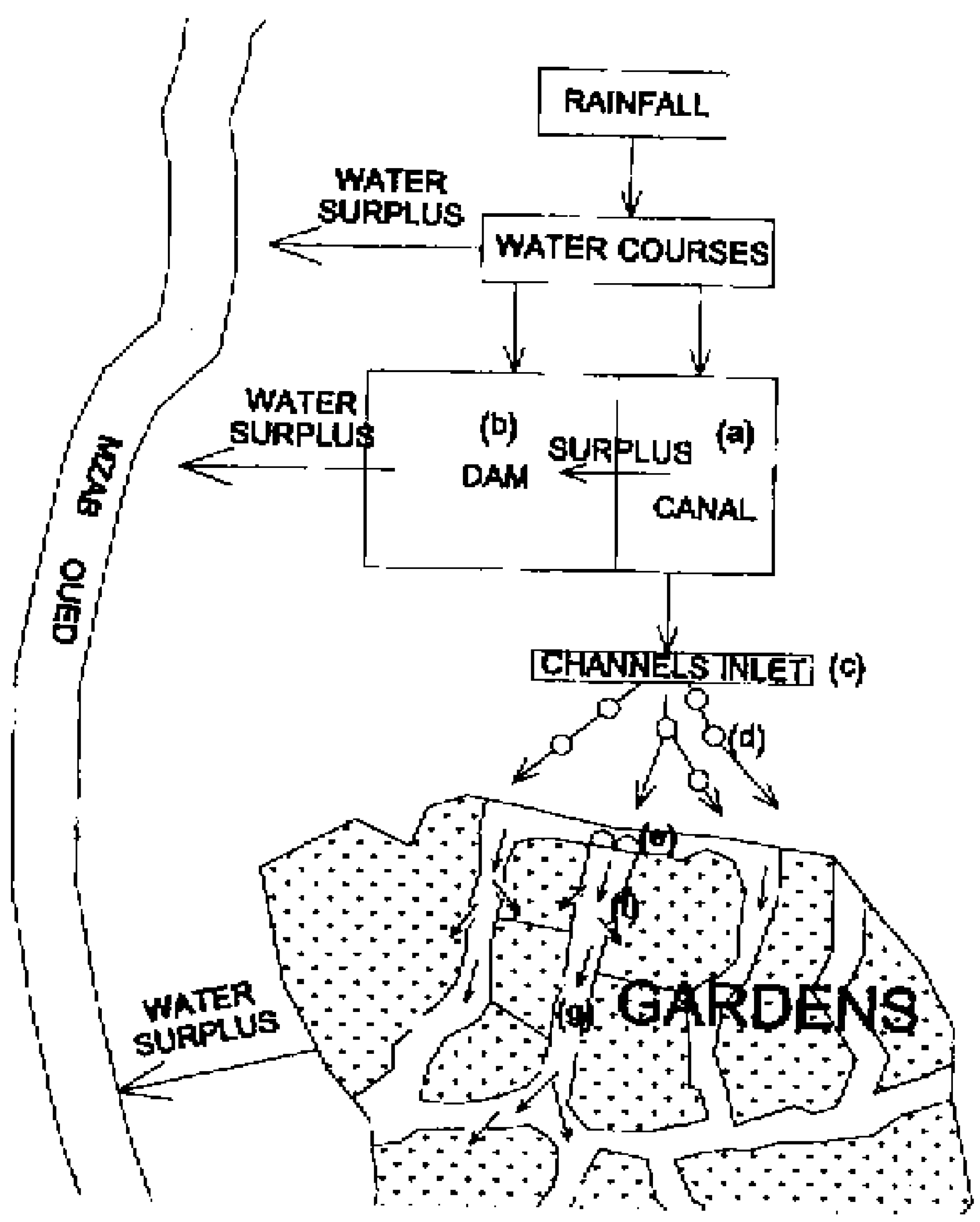



Fig. 14. Typical diagram showing how rainwater is channelled and distributed to irrigate Ghardaia gardens.

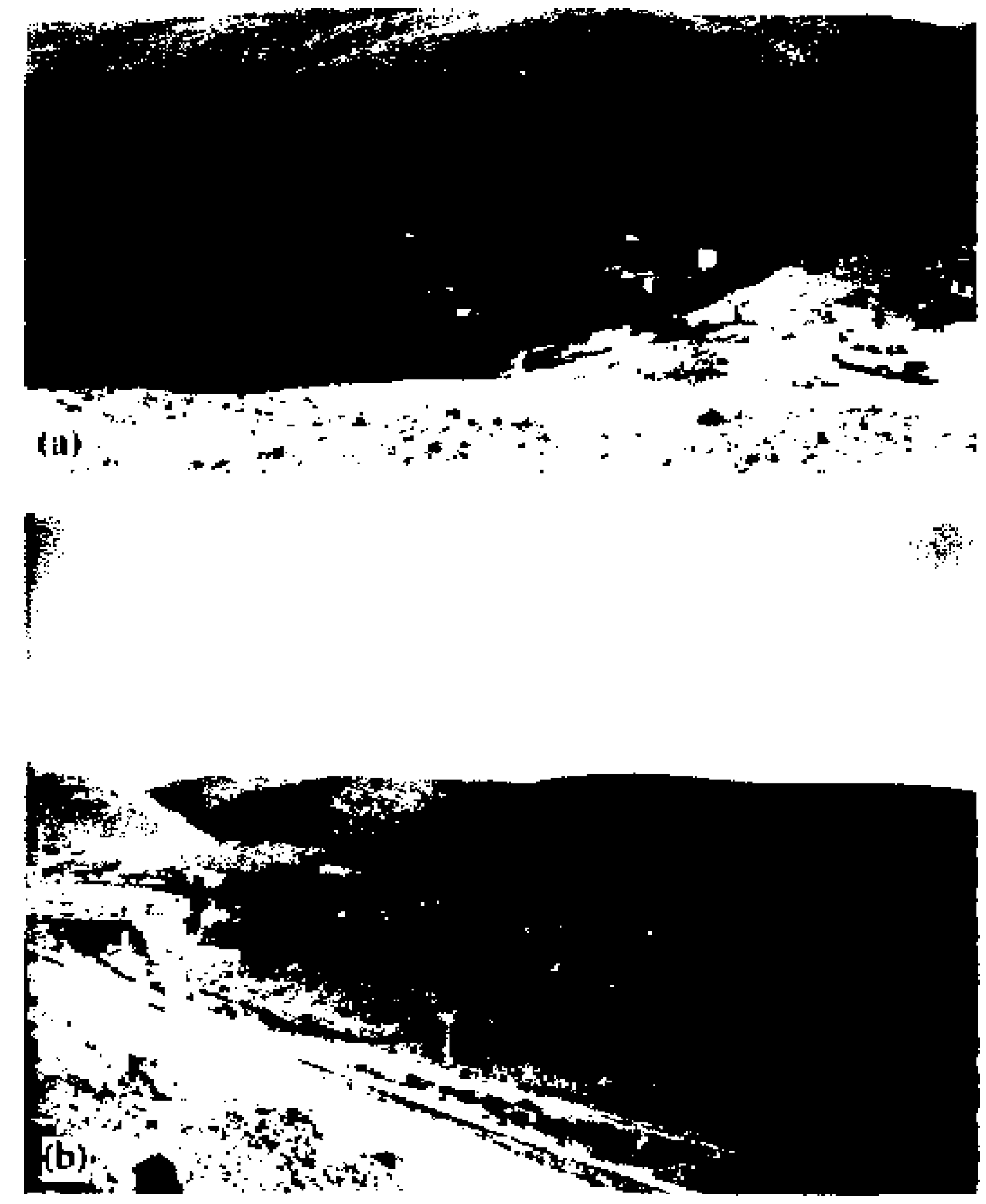


Fig. 15. Photograph showing gardens of Ghardaia and Beni-Izgen (a—Ghardaia, b—Beni-Izgen).

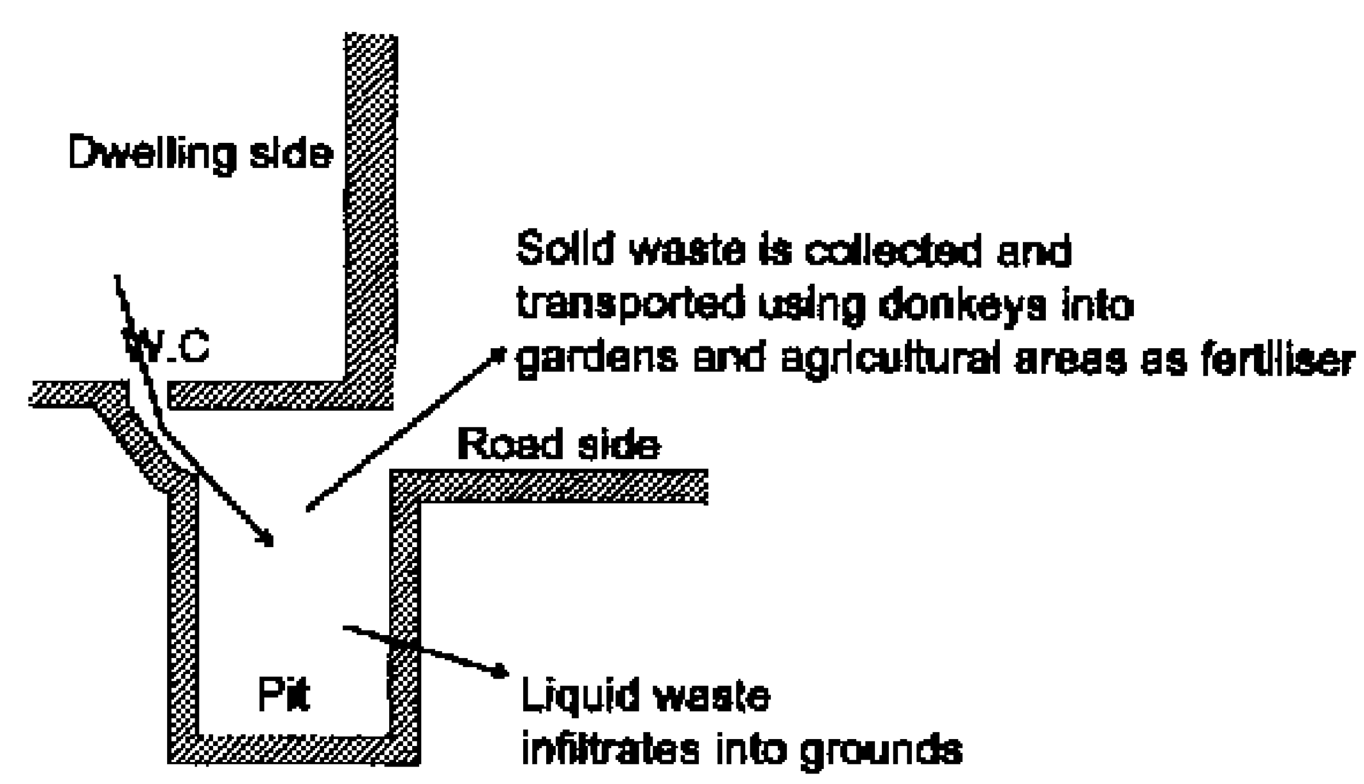



Fig. 16. Diagram showing how the waste is dealt with.

### 2.5. *Recycling waste methods*

Sanitary installations for the evacuation of wastes, rainwater and rubbish have also been given attention. Wastes from dwellings are evacuated into underground rubbish pits, which have openings through a façade of the building to allow the later recovery. A closet is fitted into a small corner on the ground floor, and has an outlet to evacuate excreta into a pit, which has an opening allowing periodic collection of residues to be used as fertilizers. Fig. 16 shows a diagram for the process of re-cycling human wastes. This is a traditional way of re-cycling waste and preserving the environment. It is also an appropriate way, in an area of eater shortage, of saving water by using compost toilets or "earth closets". Near to the closet is a shower room with a drain through its floor, discharging into the pit. Wastewater may however be discharged through a hole into the courtyard floor towards a sump in the rocky soil beneath. Rainwater is collected via pottery gutters or gargoyles at roof corners and flows down the streets, replenishing the water table and cleaning away waste (Fig. 17).


Fig. 17. Photograph showing gargoyles at roof corners to drain used and rain water.

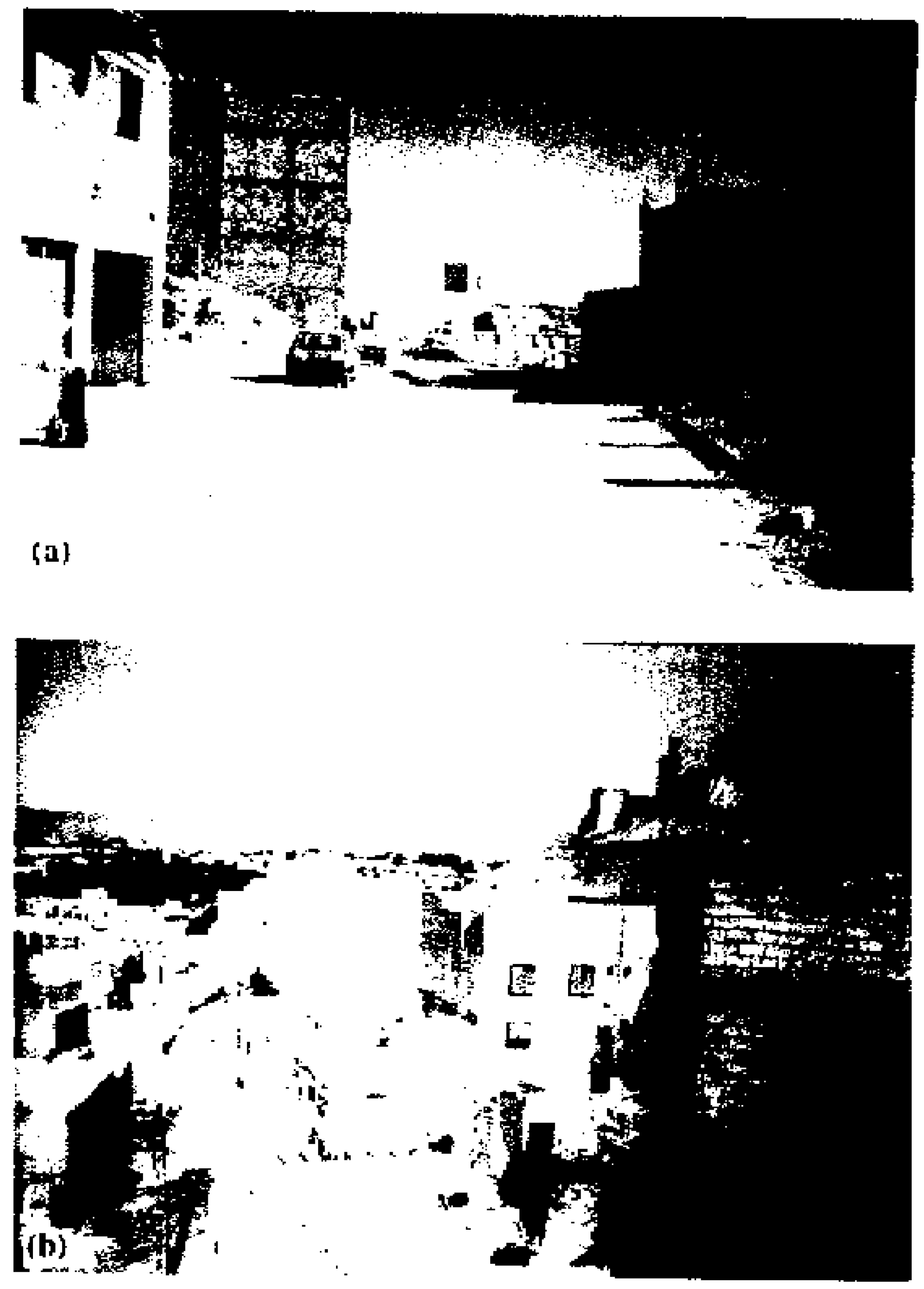
## 3. Decline of traditional practices for microenvironmental control: causes and implications

### 3.1. Main causes of the degradations of the microenvironment

A variety of factors have all combined to threaten Mzab microenvironment and its specific ecological characteristics. In fact, the actual urban climate is perturbed by the uncontrolled urbanization and new structure of the cities, by the building materials employed (nonrecycled), by the destruction of vegetation and by the pollution. This will have direct effect upon the problems of health due to pollution and heat excess, upon the comfort and the energy consumption in buildings. The valley of Mzab is developing more and more an "urban heat island".

#### 3.1.1. The "mineralization" of the valley

Concrete and the asphalt, which have high thermal absorptivity, replaced the vegetation and heat trapped by buildings and city pavements makes conditions worse. This implies low albedo and high long wave radiation emission from the surfaces. In the summer, high temperatures in combination with solar radiation and pollution produce ground level ozone and smog, which can cause serious respiratory distress, eye irritation and excessive heat. Recent years have seen resurgence in building with technologically manufactured materials rather than using the most basic natural and locally available materials (stone, mud, palm trees, lime). The builders, architects and owners are motivated by the idea that modern materials can afford them with the ease of construction and aesthetics and their buildings will survive forever, unlike traditional building materials which have a limited useful life. Quite readily we can find modern counterparts for all the basic traditional building materials. Concrete replaces stones and mud. Cement replaces lime and so on (Fig. 18). But they have ignored the fact that these materials have the disadvantages of not being environmentally responsive, they are not economic, provide less energy efficiency and do not provide ecological harmony, and they are nonrecycled and can be sources of various nuisances such as; they do not provide adequate thermal comfort inside buildings and thus, they increase air-conditioning systems demands and so additional energy costs for the citizens, they are nonrecycled materials and cause problem of wasting the environment, they have high thermal absorptivity and therefore they contribute to the "island heat effect".



(a)

(b)

Fig. 18. Photograph showing new material used (a: at Melika Ksar, b: at Melika periphery).

#### 3.1.2. Destruction of vegetation

No one can ignore the significant role that vegetation plays in an urban environment. It can change the microclimate by increasing the moisture content of the air, provide shade, filter out dust and help to prevent atmospheric pollution. It is also one of the most vital factors in maintaining the ecological balance in this region. To understand the distribution of increasing populations over the Mzab area, a site pan showing the area's growth since the last few decades revealed the extent of palm trees abolition (Fig. 19). The various factors those participate in the destruction of vegetation are:

- The lack of suitable land for buildings in the valley pushed the inhabitants to cut palm trees to get land. This will of course have a negative impact upon the ecosystem balance. This deforestation causes as well soil erosion and leads to increasing desertification.
- The introduction of industrialization as new mode of production into the region, such as Sonelgaz, Sonatrach, metallurgy, textile, plastics, Hydrocarbon, nonrecycled

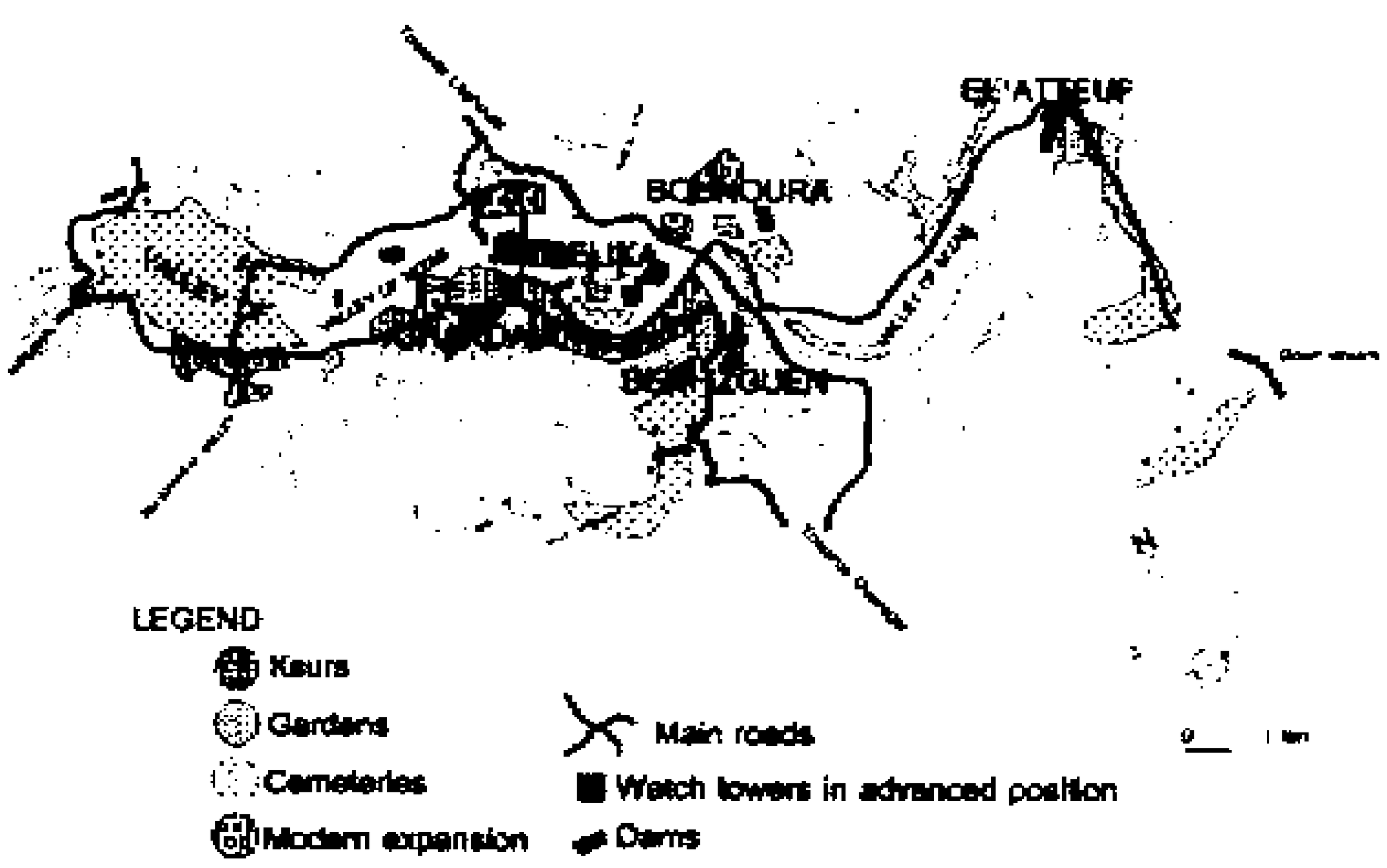



Fig. 19. General plan of Mzab valley showing how wild urbanization invades the valley bed in detriment of agricultural space and vegetation.

building materials, cloth and tents, chemicals and food products, has a consequent impact upon the regression of palm trees (Tables 1 and 2) [3]. This industry, in addition to the pollution it causes, attracts more and more the labor force in detriment of agriculture.

In 1879, Ghardaia for a population of about 11 000 inhabitant had about 80 000 palm trees [4]. This represents a proportion of 7.3 palm trees per inhabitant. El-Atteuf as well had very large gardens for only a population of 2500 inhabitants. Guerrara, the sixth settlement of Mzab, had in 1884 a number of 28 728 palm trees for 4000 inhabitants [5], which represents 7.2 palm tree per inhabitant. From Ghardaia's and Guerrara's examples, we can say that more than 7 palm trees per inhabitant are required to maintain an ecological balance.

### *3.1.3. Perturbation of the environment hydrology*

Until the last few decades, the valley of Mzab was supplied with water from superficial groundwater which depends to a large extend upon rain fall for which Mzab community established (to supply these groundwater) several dams and wells. Recently and in order to respond to the accelerated urbanization, groundwater table was discovered at about 500 m depth and was extensively used. This has, in addition to urban growth, caused significantly:

- The decline of traditional water systems (considered as sustainable systems) and the disappearance of superficial water table, which has stood for centuries in the very harsh conditions. Urbanization of the appropriate spaces to water collections and the use of traditional wells by some people as pits to discharge the waste.
- Great consumption of water which cause the running out quickly of the groundwater table and can cause shortage of water in the future, especially that the amount of water of the table is not renewed in the same way as the consumption.
- The use of too much water, especially with the introduction of modern system of sewage and water supply, has increased the humidity in the traditional buildings, which were designed and built originally with materials that go with dry environment, and this has caused the progressive deterioration of traditional buildings.

Table 1
Regression of areas and number of palm trees from year to year

| Communes | 1968 | | 1983 | | 1993 | | 2000 | |
|---|---|---|---|---|---|---|---|---|
| | Area (ha) | N.P.T | Area (ha) | N.P.T | Area (ha) | N.P.T | Area (ha) | N.P.T |
| Ghardaia | 280 | 134 260 | 170.7 | 81 832 | 201 | 96 380 | 419 | 114 253 |
| Bounoura | 110 | 10 135 | 122.5 | 11 286 | 77 | 7093 | 167 | 16 526 |
| El-Atteuf | 72 | 6177 | 157 | 13 525 | 24.4 | 2094 | 172 | 21 635 |
| Total Valley | 462 | 150 572 | 450.2 | 106 643 | 302.4 | 105 567 | 758 | 152 414 |

N.P.T = number of palm trees.

Table 2
Decrease of the number of palm trees per inhabitant from year to year

| Communes | 1968 | | 1983 | | 1993 | | 2000 | |
|---|---|---|---|---|---|---|---|---|
| | N. Pop. | PT/I | N. Pop. | PT/I | N. Pop. | PT/I | N. Pop. | PT/I |
| Ghardaia | 31 611 | 4.2 | 54 156 | 1.5 | 77 541 | 1.2 | 99 689 | 1.1 |
| Bounoura | 10 713 | 0.9 | 16 663 | 0.7 | 22 369 | 0.3 | 27 490 | 0.6 |
| El-Atteuf | 4991 | 1.2 | 7749 | 1.7 | 10 389 | 0.2 | 12 756 | 1.7 |
| Total Valley | 47 315 | 3.2 | 78 568 | 1.4 | 110 299 | 1.0 | 139 935 | 1.1 |

N. Pop. = Number of population, PT/I = palm trees per inhabitant.

- Urbanization has had significant impacts on the hydrology of the environment by controlling the nature of *runoff*, the rates of soil erosion; and the delivery of pollutants to valleys, streams and dams. In the new urban areas of Mzab valley much of the land is paved or covered by asphalt (streets and roads) and buildings. In these circumstances rainwater runs off much faster than on unpaved land. This water cannot be absorbed into the soil, it flows rapidly down storm drains or through sewer systems, contributing to floods and often carrying debris and other pollutants to streams. It is important to mention that hydrological perturbations often produce detrimental effects on both water quality and quantity. Precipitation is partly absorbed by the ground and partly becomes surface runoff. The absorbed water is divided between base flow (underground runoff to water table) and evapo-transpiration. Urbanization has caused the surface runoff to increase, and the replenishment of underground water to decrease. Impervious surfaces and sewers cause runoff after a rainstorm to occur more rapidly and with a greater peak flow than under nonurban conditions. In turn, larger peak flows increase the frequency of floods. In general we can say that urbanization increases flood volume, frequency and peak value. The net result of this flushing effect may be to increase turbidity, pollutant loads, and bank erosion.

### 3.1.4. Decline of air quality due to air pollution

The Mzab environment has been exposed to unprecedented atmospheric air pollution in recent years. The growth in the amount and complexity of air pollution brought about by urbanization, industrial development, and the increasing use of motor vehicles (Table 3), has resulted in mounting dangers to the public health, welfare and the quality of life. In the urban areas of Mzab, transportation activities contribute significantly to air pollution, greenhouse gas emissions, noise, and associated health impacts. The greenhouse gases involved are mainly; carbon dioxide; methane; nitrous oxide; chlorofluorocarbons; and tropospheric ozone. Of which, the most important gas is carbon dioxide which accounts for about 55% of the change in the intensity of the Earth's greenhouse effect. The concentration of these gases in the air create health problems and enhance the green house effect which makes the microenvironment warmer.

Monatomic gases such as helium and argon and diatomic gases such oxygen, nitrogen and hydrogen, are transparent to thermal radiation. This explains why solar radiation can travel through the atmosphere and reach the earth surface. However, the polyatomic gases such as carbon dioxide, ammonia, methane and water vapor are fairly good radiator and absorbers to thermal radiation [6]. The gas molecules gradually absorb the energy from electromagnetic waves as they travel through the gas volume. Therefore, the absorptivity of a gas volume depends not only upon its physical properties, including temperature and pressure, but also upon its shape and size. Absorption in the atmosphere is carried out by water vapor, carbon dioxide, ozone, dust and cloud particles or other impurities suspended in the atmosphere. Building surfaces in urban areas receives not only direct solar radiation but also the radiation from the atmosphere and radiation from the ground surfaces. At the same time, the surface lose heat by conduction, convection and emission. If the heat is gained more than it is lost, the temperature of the building surfaces increase and this will have a direct impact upon thermal comfort. Radiation from atmosphere varies widely with the time of the day. At night, when the solar radiation is cut off, the sky temperature is low. This allows inhabitants to benefit from radiative cooling at night. But this is not the case when the atmosphere is full of greenhouse gases issued from pollution and dust particles.

Table 3
Evolution of vehicles in the valley of Mzab in the last few decades

| Type of vehicles | Years | | | |
|---|---|---|---|---|
| | *1985* | *1990* | *1995* | *2000* |
| *Cars* | 589 | 3489 | 5898 | 9632 |
| *Lorries* | 279 | 1661 | 2640 | 3843 |
| *Vans* | 524 | 2173 | 3406 | 5355 |
| *Buses* | 6 | 23 | 158 | 379 |
| Total | 1398 | 7346 | 12 102 | 19 209 |

### 3.1.5. The urban forms

The transformation process from traditional compact urban forms into scattered forms and the use of modern materials in new buildings increased the use of air-conditioning systems which lead to higher energy costs and increased emissions due to higher power generation.

## 3.2. Implications of such degradation

The main implication caused by the above-mentioned factors is the build-up of a heat island in the Mzab urban environment and the reduction of comfort conditions for the inhabitants.

### 3.2.1. The heat island effect

The heat island is the increase of ambient temperature of urban environment in comparison to a nearby rural environment. This is associated usually with; high pollution of the atmospheric air, low air movement and the formation of a dome of overheated and polluted air. The heating of the ground by the sun causes the surface of the earth to absorb most of it and re-radiate long-wave energy to the atmosphere whereby it is absorbed partially and is then reflected many times within this enclosure with partial absorption at each contact with a surface. Absorption of this energy causes additional heat energy to be added to the earth's atmospheric system. The amount of heat energy added to the atmosphere by the greenhouse effect depends to some extends to the

Table 4
Mean air temperature at different periods to show the heat island effect

| | Tm (°C) 1995–1999 | Tm (°C) 1950–1955 | ΔT(°C) |
|---|---|---|---|
| January | 11.8 | 10.1 | +1.7 |
| February | 13.5 | 12.6 | +0.9 |
| March | 16.2 | 16.0 | +0.2 |
| April | 20.2 | 19.7 | +0.5 |
| May | 25.9 | 26.1 | +0.2 |
| June | 31.0 | 31.4 | −0.4 |
| July | 33.8 | 33.9 | −0.1 |
| August | 34.1 | 31.7 | +2.4 |
| September | 28.7 | 27.4 | +1.3 |
| October | 22.1 | 20.6 | +1.5 |
| November | 16.5 | 17.5 | −1 |
| December | 13.4 | 12.0 | +1.4 |

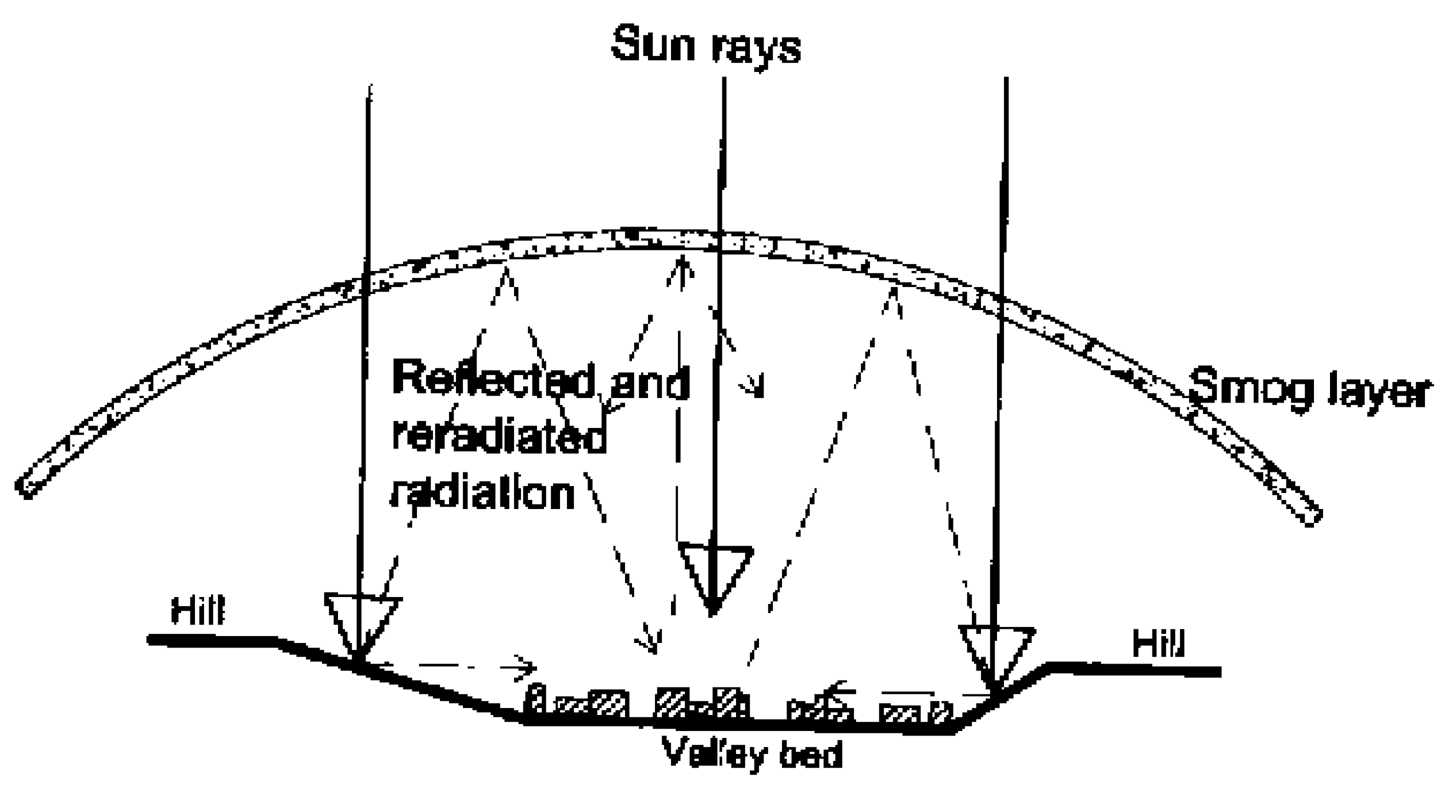


Fig. 20. Diagram showing the urban heat island smog formation due to the wild and unstudied urbanization on the valley bed.

concentration of greenhouse gases in the atmosphere near the ground.

There are three main factors causing urban heat island in the valley of Mzab:

- The replacement of natural vegetation by heat-absorbing surfaces such as building roofs and walls, parking areas, and streets. As a result, solar energy is absorbed into roads and rooftops, causing the surface temperature of urban structures to become higher and cause the increase of overall ambient air temperature. This phenomenon raises air temperature in the valley by 2.5°C (Table 4).
- Heat emission by human activities: by introducing industrial activities to the region, "embodied energy" is increased. The total amount of energy required to bring a material into existence is called "embodied energy." This includes all the energy needed to mine, transport, process, distribute, and more. The cumulative energy embodied in creating and transporting the materials and systems of a building may actually exceed the energy required to heat and cool the building for 10–30 years.
- Air pollution in urban areas is high and the particles will form a shield for trapping heat (Fig. 20). During hot months a heat island creates considerable discomfort and stress and also increases air-conditioning loads and accelerates the formation of urban harmful smog, as ozone precursors such as nitrous oxides ($NO_x$) and volatile organic compounds (VOCs) combine photochemically to produce ground level ozone.


Fig. 21. Photograph showing air-conditioning systems are extensively used to establish thermal comfort instead of traditional techniques.

In such conditions, the external environmental temperature [7] may well increase and can cause thermal discomfort. As a result, demand for cooling energy in buildings increases and can cost consumers more additional money in air-conditioning bills in order to maintain thermal comfort. In addition, increased electricity generation by power plants leads to higher emissions of sulfur dioxide, carbon monoxide, nitrous oxides, and suspended particles, as well as carbon dioxide.

### 3.2.2. *Regression of thermal comfort conditions*

In order to evaluate past and present thermal sensation conditions at the urban scale, a field subjective survey was carried with 25 subjects of the age of 70 years old of Mzab inhabitants. All responding subjects who lived in this area in the 60s revealed that in the last few decades, the climate has changed and the microclimate has been felt more and more hot.

The introduction of modern mechanical and artificial devices seems to have created a situation in which the inhabitants no longer associate themselves with the desert, its climate and its requirements (Fig. 21). It is doubtful that there are many people today in these areas who have been exposed to the desert living and who could survive in such environment without sophisticated life-support systems. If this trend continues, the dependence on energy intensive systems will continue to rise, instead of the time-tested principles in meeting climatic circumstances.

In order to evaluate thermal comfort conditions within buildings, a thermal comfort field subjective survey was carried out in two sets of buildings; traditional buildings in the ksurs (of Ghardaia and of Melika) and new modern buildings in the expansion situated on the valley bed. All responding subjects who lived in the buildings surveyed are from age 20–60 years and with an average occupancy of

5 persons per building. The subjective survey involves collecting data using questionnaires. A total of 20 subjects from traditional buildings and 20 subjects from modern buildings were questioned about occupants' perceptions of the environmental conditions in the whole building and their general feeling of thermal comfort. The table shows the comparison of the overall thermal comfort sensation for traditional and new modern buildings.

The field investigation studied the overall impression of the indoor thermal environment, and the results suggest that people have an overall impression of higher standard of thermal comfort in traditional buildings than in new ones.

## 4. Strategies and solutions for an ecosystem balance and for an urban heat island mitigation

The previously identified factors which caused the decline of the ecosystem and the widespread of the urban heat island of Mzab can be reduced through the implementation of the following recommended measures and management options:

If the nature can help to cleanse the air of pollutants in many different ways. One of which is through the dilution of pollutants (particles and dust) when it gets raining. You can clearly see the difference in the air after a shower—the sky looks clearer and the air more freshly. If the wind speed is high and turbulent the pollutants get diluted and will be less effective. Plants absorb carbon dioxide which is a major green house gas during photosynthesis and release oxygen. This unfortunately valid for coastal areas in the North of the country. Unfortunately, the South has not these natural features. The climate is very dry and vegetation is scarce.

### *4.1. Prevent further urbanization on the valley bed and establish special regulations to protect further destruction of the natural environment*

The growth in population will automatically lead to increasing levels of pollution. To control this we mainly need to consume just the right amount of natural resources and man made products, and to learn how to share resources (example: car pooling). Scientists are also looking at ways to manufacture goods more efficiently and using less materials. There is a need to avoid using items that have little value (example: plastic packing). However, it is vital to declare this sensitive oasis ecosystem a special area and promulgates specific regulations for its preservation. Urbanization should be oriented elsewhere outside the valley.

### *4.2. Trees planting as a cooling strategy*

The valley suffers from lack of agricultural spaces and thus it is necessary to put an end to the urbanization of the valley plateau in order to preserve the remaining few palm trees. It is vital to launch a program of implanting vegetation to enhance the ecological system balance and can provide significant environmental and economic benefits for the Mzab community. One of the simplest and cheapest strategies for countering the urban heat island effect is to increase the number of trees and other plants. Vegetation cools directly by shading and indirectly through evapotranspiration, the process by which plants release water vapor. This can greatly reduce a building's cooling load. This fact sheet focuses primarily on the use of trees as a method of cooling urban areas.

Trees have great potential to cool cities by shading and by evapotranspiration from the leaves. The water draws heat as it evaporates, cooling the surrounding air. Trees absorb sound, provide shade and reduce wind speed, filter pollutants from the air. They provide habitat for animals, birds and insects. They stabilise soil and prevent erosion.

Planting trees and vegetation can help reduce urban temperatures and make the valley greener. However, planting trees haphazardly throughout a city is not the best way to achieve their benefits. Within 10–15 years—the time it takes a tree to grow to a useful size—properly placed trees can reduce heating and cooling costs by an average of 10–20%. Over their lives, trees can be much less expensive than air conditioners and the energy needed to run them.

Correct selection and location of trees is important to achieve the best results. Two proven methods maximize benefits:

Deciduous trees shading the south and west sides of a building block the summer sun. Vegetation should also shade your air conditioner, which works more efficiently when kept cool. Vegetation on the northwest can protect buildings from cold winter winds. Trees grouped together create a refreshing park or oasis in a city and also cool nearby neighborhoods. Grouped trees can protect each other from the sun and wind, making them more likely to grow to maturity and live longer. The number of trees per inhabitant should not be less than 7 to maintain ecological balance.

The reuse of treated wastewater enables the sustainability of irrigated agriculture. The valley of Mzab with a population of 128 087 inhabitant and water consumption of 200 l/day/person would produce 7 947 798.4 $m^3$/year, assuming 85% of the consumption inflows to the public sewerage system. This will enables the irrigation of an area of 504 ha per year, assuming 0.5 l/ha/s. Or in terms of palm trees, this quantity will irrigate 50 400–80 640 palm trees per year, knowing that 1 ha can be occupied with 100–160 palm trees. In addition to the economic benefit of the water, the fertilizer value of the effluent is of importance. Although wastewater reuse has many advantages and benefits, it may generate environmental problems if it is not carried out properly. Inadequate reuse may cause public health risks and environmental nuisances, such as odors, aesthetic problems, and pollution of water sources (mainly groundwater) and of soil. One of the important prerequisites of wastewater reuse is therefore adequate design and construction of such project as to ensure environmental safety. Wastewater can also be used for superficial groundwater recharge. Wastewater reuse can generally be successful in (arid and semi-arid regions) zones which suffer of water scarcity, in which there is demand of water for agriculture. This happens when fresh water volumes devoted for agriculture declines because of increasing demand for the public water supply. It is also arises when traditional agricultural communities have run out of groundwater sources.

### 4.3. *Use of high reflectivity surfaces*

Of the methods for reducing excessive heat in urban areas, the use of reflective or high-albedo surfaces of buildings and pavements which are more reflective of the sun's energy (usually light-colored surfaces) and can therefore greatly reduce a building's cooling load. High emissivity or dark materials absorb more heat from the sun than a whiter one. If those dark surfaces are roofs or walls some of the heat collected by these is transferred inside. Staying comfortable in under a dark shingle roof often means more air conditioning and higher utility bills. Black surfaces in the sun can become up to 40°C hotter than the most reflective white surfaces. Van Straten [8] measured the outside surface temperatures of galvanized steel roofs with different colours in South Africa and observed that a black roof reached 70°C, while a white one, only 44°C. Whitewashing a clay tile roof reduced the ceiling heat flux by 66% [9]. Givoni [10] observed reductions of 3.5 K on ceiling temperatures when a red cement tile roof was whitewashed.

### 4.4. *Efficient energy management and reduction of artificial energy emission*

Air pollution is related with combustion and energy consumption. With increased industrial activities and vehicular movement and modernization, the energy consumption increases which increases fuel consumption and increase the air pollution. One way of controlling air pollution is by decreasing the energy consumption, which would need people's cooperation and the other way, is through cleaner technology and laws.

Decision-makers of both government and private sectors should cooperate to develop alternative fuel systems, motor drives and infrastructures to augment overall efficiency within the energy and transport sectors. Since energy consumption is one of the biggest sources of greenhouse gases, efficient energy management in cities, which includes the efficient management of energy supply and energy usage, is very important to control greenhouse gases.

Reduction of artificial energy emission should concern all the energy needed to mine, transport, process, distribute, and air-conditioning. Communities can decrease their demand for energy and effectively cool the urban environment. In addition to the economic benefits, using less energy leads to reductions in emissions of greenhouse gases. The total amount of energy required to bring a material into existence is called embodied energy. The cumulative energy embodied in creating and transporting the materials and systems of a building may actually exceed the energy required to heat and cool the building many times.

The authorities should ban burning wastes and leaves in urban areas. The burning releases huge quantities of smoke (mainly particles matter) and this can be severe in winters. The problem can indeed become acute and more of a concern if along with the leaves, plastic, discarded cells, etc. is burnt.

### 4.5. *Use renewable and recycled resources*

The use of renewable resources means using solar, wind, and geothermal energy sources as much as possible. Many common building materials come from renewable sources including wood. But there are other considerations as well, like the harvesting method. Some nonrenewable resources may actually be used many times or ⟨⟨recycled⟩⟩. This is true, for example, of many metals. Recycling reduces the disruptive and polluting effects of virgin mineral extraction. So do water-reuse technologies and the use of many agricultural and industrial by-products. Building materials should be a recycled resource, not a waste sent to a landfill after the building's useful life.

### 4.6. *Prevention and control of air pollution*

Air pollution prevention—that is, the reduction or elimination, of the amount of pollutants produced or created at the source—and air pollution control at its source is the primary responsibility of the government and local authorities. Air quality management is a critical problem in many cities of Algeria. However, administrators and decision makers in local authorities, institutions, and communities should cooperate to protect and enhance the quality of the air resources so as to promote the public health and welfare of its population. This could be by implementation of measures that can effectively monitor, control and prevent pollution and reduce the impacts of air pollution in Mzab towns.

To help alleviate this growing problem, authorities should take multi-pronged approach to attempt to lessen the problem:

- The applications of new technology 'Intelligent Transport Systems' to the management and control of urban transport should be pursued as a major priority in Mzab valley.
- Local government actions to oblige individuals to pay high taxes on the use of private cars and more energy emission.
- Reduction of vehicle Kilometers travelled should be sought through urban planning and transit system design,

which both allows and encourages the enhanced use of public transport and alternatives such as walking or bicycling for shorter journeys.

Roads are built to accommodate a certain capacity of people, after that level is reached, each additional vehicle slows down the other cars on the road thus imposing a longer traveling time of all of the other drivers. Furthermore, automobiles produce air pollution, which is another eternality, which affects the population of Mzab.

- An area-licensing scheme should be enacted. This area-licensing scheme defines a restricted zone in the urban area of the valley. This scheme restricts use of the roads in the central business district at least during the peak hours. Only cars, which display a license, are allowed to enter this zone. This regulation was first applied in Singapore city [11]. The area-licensing scheme was extremely successful in reducing traffic congestion during the peak hours. By the fourth week of the ALS, traffic flow during the peak hours had fallen by 45.3% [11].

## 5. Conclusion

In the last few decades, urbanization of the valley of Mzab has exacerbated. Its impact on the natural environment and ecosystem balance has become a major preoccupation. The microenvironment of the valley is disturbed by the new urban expansions, the abolition of vegetation, the new materials employed and by industrial activities which have developed. Modifying the microenvironment will act directly on public health, thermal comfort and on the energy consumption in buildings.

Our investigation showed how the space was used by the Mzab traditional society to adapt with the surrounding hostile environment and the magnitude of how land use has changed over the past few decades. It has revealed that Mzab valley has become an island into another in recent years. It has developed an "urban heat island" that have temperatures up to 2.5°C higher than what use to be 50 years ago. Mzab area is warmed by its own urban heat island as a result of the removal of vegetation, the use of heat-absorbing materials for walls roofs and roads, and increased air pollution. The added heat intensifies Mzab air quality problem. The city is plagued with serious ozone pollution. Smog levels are intensified by the urban heat island because with a 10° rise in temperature, the chemical reaction that creates ozone-the molecule responsible for smog-doubles. Ozone is only produced in warm summer months.

This paper is oriented towards creating a strategic vision and developing action plans for environmental protection. Seeking solutions for the problems imposed by the urban expansion of the valley seems to be complicated, at least in the near future. However, with the participation of all protagonists locally, nationally and internationally we may be able to resolve some of the nuisances in the long term. My recommendations to prevent further decline of the ecosystem balance, to re-establish the environmental qualities and to mitigate urban heat island effect, lie in the implementation of the following measures:

- prevention further urbanization of the valley,
- plantation of more vegetation,
- use of high reflectivity surfaces,
- efficient energy management and reduction of artificial energy emission,
- and the use renewable and recycled resources.

At the end, I believe that, the survival and future well-being of the Mzab ecosystem is at stake, and requires effective management if the environment is to be adequately protected. Only through collective effort will further destruction of traditional settlements, ecological balance and the sustainability of this area be prevented. Architects and professionals working in this area have too long ignored the ecological balance, which relies upon the above measures, and it is time to be considered for future planning developments. It is the responsibility of the designer to use available resources to optimum advantage and try to guide his client in choosing the best available alternatives.

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