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• *Water – Fog harvesting – Rural communities – Feasibility study – Ifni, Morocco*

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# Fog Water Harvesting in Ifni, Morocco. An Assessment of Potential and Demand

*Nebelwassergewinnung in Ifni, Marokko. Eine Bewertung des Potenzials und der Nachfrage*

With 9 Figures, 4 Tables and 5 Photos

This pilot experiment explores the feasibility of harvesting fog water in the Ifni region, Morocco, to help a small community that lives in an arid region and that needs this water. Four Standard Fog Collectors were installed at two mountain sites in the Ifni region, and these have been providing good quality data since June 2006. The results show that it is possible to obtain an average of 7.1 litres per $m^2$ per day at the inland site whereas only 1.9 $l/m^2$/day were obtained on the coast. Variations, caused by the regional topography, in the direction of the wet winds from the Atlantic Ocean, which create the fog, determine the most suitable sites for the fog water harvesting.

## 1. Introduction

In June 2006 the Si Hmad Derham Foundation (Morocco) and the University of La Laguna (Canary Islands) began a project to evaluate the viability of using water from fog (*tagut* in the Berber language) for the local communities on the coast and inland near Ifni (Morocco). Two sites were chosen: Boulaalam, 300 metres above sea level, and Boutmezguida, 1,225 m a.s.l.

The technology of artificially obtaining water from fog in deserts has been successfully tried and tested in various parts of the world, not only for supply to humans (e.g. *Schemenauer* and *Cereceda* 1991, 1994; *Cereceda* and *Schemenauer* 1996; *Olivier* and *Heerden* 1999; *Olivier* and *Rautenbach* 2002; *Marzol* 2002) but also for forestry use (e.g. *Baynton* 1996, *Winsch* and *Harris* 1994, *Aboal* et al. 2000, *DeFelice* 2002 etc.). The quality of this water has been shown to be acceptable for human consumption (*Schemenauer* and *Cereceda* 1992, *Marzol* 2005).

The interest in research on fog water collection does not lie in the application of novel methodologies or in using new instrumentation and sources, because previous studies have already validated these analytical phases. The real interest in these studies is the future application. In the case of the Atlantic coast of Morocco, our results suggest that the use of fog water is efficient because a good quantity is collected. But what really matters is that this resource will be of use to improve the quality of life of certain rural communities, about 1,000 people. It could alleviate the exodus of people in rural areas, reduce the time women spend working, and allow more time for schooling – because it is the women's and children's task to fetch water – , thereby contributing to sustainable development and to conserving traditional activities in these areas.

The viability of the applied phase of the project requires, on the one hand, external funding for the installation of the larger-size screens (larger fog collectors, LFCs) and the storage tanks and, on the other hand, the indispensable participation and involvement of the local community in maintaining and managing the installations.

## 2. The Research Area: Ifni Region, Morocco

### *2.1 Essential geographical features*

Ifni is a region located on the Atlantic coast of Morocco (29º N; 10º W), with a surface area of 1,310 km$^2$ and a population of 64,269 inhabitants distributed among 348 villages. Ifni belongs to Tiznit province (Souss-Massa-Draâ), locally known as Aït Baarmrane. This region is situated on the same latitude as the Canary Islands, only 300 km east of the island of Lanzarote (*Fig. 1*).

The capital of the Ifni region, Sidi Ifni, has a population of 20,000 and is located to the SW of the Anti-Atlas mountainous system, on a narrow terrace 60 m

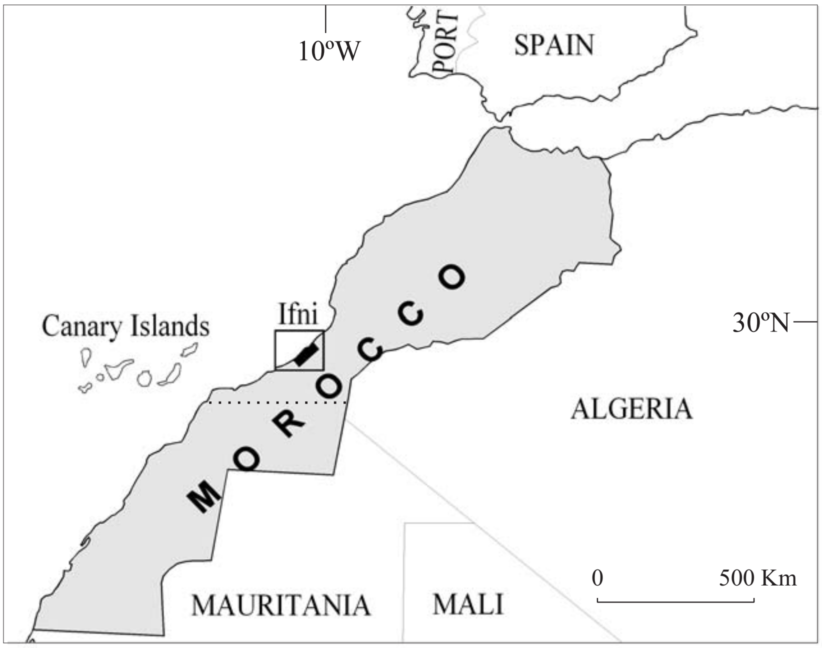


*Fig. 1* Location of Ifni region in Morocco / *Lage der Region Ifni in Marokko*

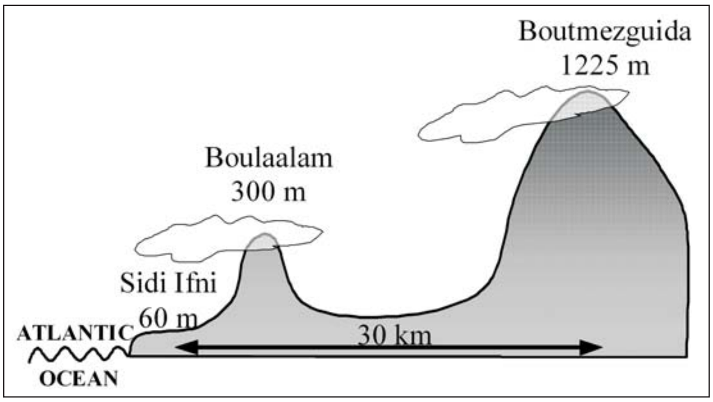


*Fig. 2* Schematic profile of the research area with the experiment sites / *Schematisches Profil des Untersuchungsgebiets mit den Versuchsstandorten*

a.s.l. between a mountainous coastal alignment of an altitude of about 350 m and a coastal cliff. This small region of Morocco was a Spanish province from 1904 to 1969. Mount Boutmezguida, one of the sites where the fog water collection experiment was performed, is located in an inland mountainous area with altitudes of more than 1,200 m a.s.l. (*Fig. 2*).

The first site chosen is Boulaalam (29º 21' 85" N; 10º 10' 22" W) which is located on the summit of

*Photo 1* Sites of SFC No. 1 (WNW-exposed) and SFC No. 2 (NNW-exposed) in Boulaalam (300 m a.s.l.), open to the wet Atlantic winds, with the city of Sidi Ifni in the background / *Standort der Standard-Nebelwassersammler (SFC) Nr. 1 (WNW-exponiert) und Nr. 2 (NNW-exponiert) in Boulaalam (300 m ü. NN), den feuchten Atlantikwinden ausgesetzt, mit der Stadt Sidi Ifni im Hintergrund*

*Tab. 1* Average values of meteorological variables at Sidi Ifni airport (1994-2000)
*Durchschnittswerte meteorologischer Merkmale für den Flughafen von Sidi Ifni (1994-2000)*

| MONTH | Rain mm | Humidity % | Sunshine/day hours | Average temperature ºC | Number of fog days 1941-1947* |
|---|---|---|---|---|---|
| January | 19,7 | 66 | 7 | 17,1 | 1 |
| February | 9,6 | 68 | 8 | 17,8 | 2 |
| March | 8,9 | 67 | 8 | 19,2 | 2 |
| April | 6,2 | 79 | 8 | 18,3 | 1 |
| May | 1,7 | 82 | 8 | 18,9 | 6 |
| June | 2,0 | 84 | 4 | 20,2 | 6 |
| July | 1,5 | 86 | 5 | 20,8 | 7 |
| August | 0,6 | 86 | 6 | 21,3 | 6 |
| September | 1,9 | 84 | 6 | 21,0 | 6 |
| October | 8,0 | 75 | 7 | 21,4 | 4 |
| November | 13,7 | 67 | 7 | 20,0 | 1 |
| December | 25,3 | 68 | 7 | 18,2 | 1 |
| **YEAR** | **99,1** | **76** | **81** | **19,5** | **43** |

Sources: Moroccan Meteorological Office; * *Font Tullot* 1949

the coastal hills, very close to the capital Sidi Ifni, 4 km from the coast and at an altitude of 300 m a.s.l. (*Fig. 2* and *Photo 1*). The second site is Boutmezguida (29º 12' 30" N; 10º 01' 30" W), also on the summit of a mountainous elevation, at 1,225 m a.s.l., and 30 km inland southeast of Sidi Ifni. Both sites are of great biological and ecological interest because of the diversity of plant species representative for the flora in Macaronesia, and they both have an abundance of aromatic and medicinal plants (*Echium plantagineum*, *Euphorbia regis-jubae* and *peplis*, *Senecio antheuphorbium*, *Ricinus communis*, *Diplotaxis harra*, *Caralluma marocana*, *Heliotropium ramosissimum*, *Capparis spinosa*, *Rumex vesicarius* etc.). The Boutmezguida mountainous area is catalogued as an Important Zone for Plants and the Moroccan authorities are considering its protection at a national level to preserve its biodiversity and environment (*Montmollin* and *Radford* 2004). In addition, the existence of lichens on the rocks and on the vegetation, even on cactuses, is a good indicator of the frequent presence of fog and this reaffirms the choice of these two places for performing this experiment.

The four Standard Fog Collectors (SFCs) were installed (two SFCs at Boulaalam and two at Boutmezguida) in an altitudinal transect between 300 m and 1,225 m a.s.l. to study the effect of altitude and the orientation of the local relief on the dimension of fog water collected. Two SFCs with differing orientations were placed at each site: at angles of 300º and 340º because *a priori* these were the common directions for fog-bearing winds. Thus, at the end of the analysis period it will be possible to determine which wind direction is most favourable for an optimal fog water collection, and this information will be used at a later stage when larger-sized screens will be erected.

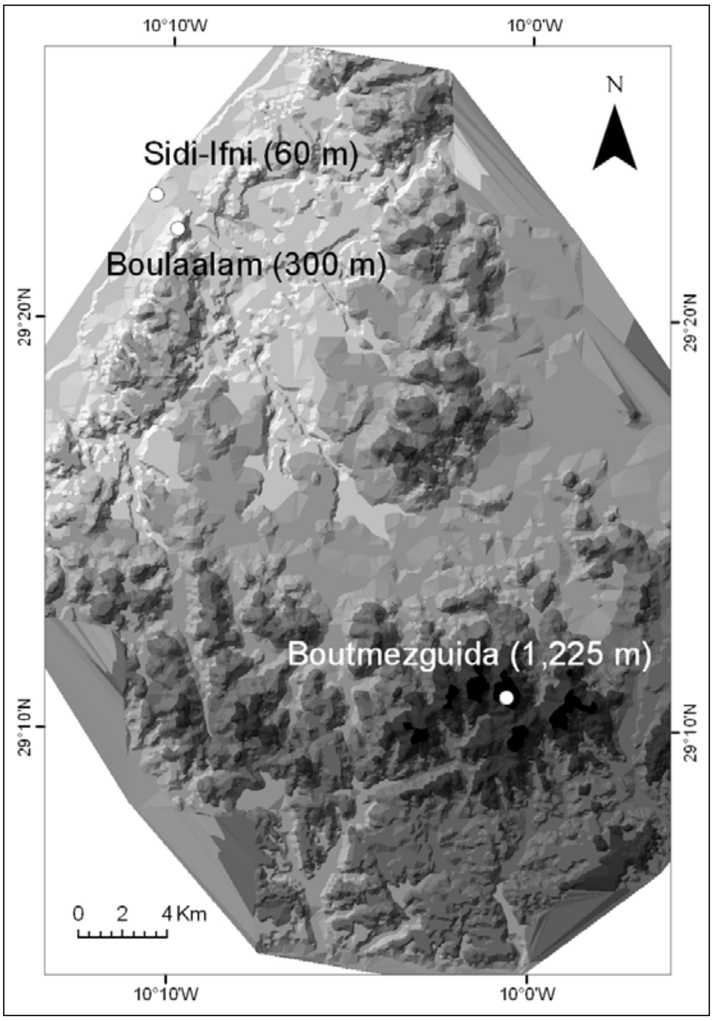


*Fig. 3* Elevation model of the Ifni region. The peculiarities of the climate in Ifni area are a consequence of its location between the Atlantic coast and the Anti-Atlas mountain system.
*Höhenmodell der Region Ifni. Die Eigenschaften des Klimas in Ifni resultieren aus der Lage zwischen der Atlantikküste und dem Antiatlas-Gebirge.*

### *2.2 Climatic conditions of Ifni*

The climate in this part of the Moroccan Atlantic coast is that of a desert, characterised by scarce annual precipitation (< 150 mm) concentrated in the three winter months (54 % of the annual total). However, cloudiness and relative humidity are high, especially during the summer (> 87 % of humidity) when trade winds bring stratocumulus clouds that predominate below 1,200 m (*Tab. 1*). Air temperatures on the coast are moderate (19.5ºC annual average), even in the summer the average monthly temperature does not exceed 22ºC; excessive heat, over 35ºC, only occurs on a limited number of days in the year coinciding with the hot dry *Cherguis* winds from the Sahara. The average annual thermal amplitude is less than 6ºC on the coast and doubles in the inland part of the territory. Another climatic characteristic of this Atlantic region are the low values of sunshine hours, less than 7 hours a day.

Stratiform clouds are possibly the most frequent and characteristic feature of this Atlantic coast, with a high number of fog days, above all in the summer (*Font Tullot* 1949, *Delannoy* 1980). At this time of the year the wet oceanic air cools as it flows over the cold waters of the Canary sea current; and it is compressed by an inversion layer, thereby increasing its stability and facilitating the formation of low-lying cloudiness that, on reaching the African continent, hits the coastal relief more easily (*Marzol* et al. 2007). The information on fog days at Sidi Ifni airport, 60 m a.s.l., three km from Mount Boulaalam, is of little use in this study because it differs substantially from what really happens on the Boulaalam summit, 300 m a.s.l. Thus, whereas the number of fog days in Sidi Ifni is reported as 43 (*Font Tullot* 1949), in 2006 and 2007 we collected fog water in the SFCs on the coastal mountains on 161 days on an average (*Tab. 1* and *3*). The explanation for this is the different altitude of both places: 60 metres against 300 m a.s.l.

The atmospheric circulation along the NW African coastline is dominated by the following three types of circulation and weather systems:

a) the NNE trade winds driven by the Azores anticyclone, more intense and frequent in summer, bringing low clouds and fog;

b) frontal depressions from the mid-latitude which are responsible for the scarce winter rains;

c) the warm dry winds from within the Sahara (*Dubief* 1961; *Ben Brahim* 2001, 2003).

With regard to the three atmospheric patterns, the first one provides the appropriate conditions for extracting the liquid contents of the stratocumulus clouds – or fog – artificially, whereas the second provides conventional rain and the third raises the temperature abruptly thereby reducing the possibility of fog water yields. The stratocumulus clouds are detained by the mountainous coastal system and give rise to the frequent fog on the Ifni coast, which is then channelled through a wide valley until it reaches the higher inland mountains more than 30 km away from the coast (*Fig. 3*). The complicated topography is the reason for the significant and fast local variations in climate from the coast to the inland mountainous region, not only as far as temperatures, precipitation and winds are concerned but also with regard to cloudiness, which is much more common on the coast than inland (*Font Tullot* 1948).

The climatic study of the fog dynamics and its potential as source for potable water must be accompanied by a socio-economic analysis of the water needs of the rural population, as well as of the final economic costs of the production of water from fog (materials, pipelines and maintenance) that *Cereceda* et al. (1993, *Cereceda* and *Schemenauer* 1993) put at 2 US $/m$^3$ of collected water when the distance between the screens and storage tanks is no more than 6 km. Despite its eminently climatic character, this study does not ignore the relevance of these latter questions.

### *2.3 Socioeconomic aspects in the research area with regard to water supply*

The region's economy is based on fishing, marginal agriculture (only 27 % of the land is cultivated, mainly by wheat, due to the poor quality of the soil and scarcity of rain) and livestock farming. All these activities rely heavily on water, a resource which is becoming scarcer as well as being one which determines the lives of the local population.

The socioeconomic surveys conducted on the Boutmezguida population suggest that the average daily water consumption per person is 15 litres, for goats and sheep it is 1 litre, and for cows, asses and camels about 10 litres. All potable water comes from public wells at the *uadis* and private family cisterns which collect rainfall water. The average size of these family cisterns is 15,000

*Photo 2* Goats are the main source of income for the families in the Boutmezguida valley (e.g. sale and consumption of meat and milk) but they also contribute to soil erosion. / *Ziegen sind die Haupteinkommensquelle für die Familien im Boutmezguida-Tal (z. B. durch Verkauf und Verzehr von Fleisch und Milch) aber sie tragen auch zur Bodenerosion bei.*

litres and the water is only used for domestic purposes (e.g. washing, cooking, making tea and as water for the animals) but not as drinking water for the humans. In times of drought, both types of wells are dry and the people are forced to buy water which costs 300 Dirhams (DH) for 5,000 litres (1€ = 10.88 DH), which is a lot of money for the local population, or look for water in nearby valleys. This has forced the rural population to buy water at a high price, to move the beehives to the north in search of water and to travel greater distances with their livestock to find suitable pastureland. It is the women and children who do this work involving a walk of between 1 and 9 km a day. The case of *Mohmmad Sfourg* (a bee-keeper), who has a family of 10 who look after goats, cows and an ass which need 500 litres of water per day, which means about 15,000 litres a month (i.e. 900 DH/month when your monthly salary is 1,000 DH), is an example of water needs and the reason why there has been an exodus from this rural region.

The population census and the animal head-count carried out in the valleys around Mount Boutmezguida reveal that 161 families (897 people) live in this area and look after 7,000 animals (5,455 goats, 1,400 sheep, 129 cows, 10 donkeys and 6 camels). The possibility of supplying water from fog to this desert area with low rainfall increases the chances that these traditional activities may continue and that an improved standard of living may be provided for the rural population there. Essentially speaking, the inland rural population lives in the valleys and takes their livestock up the mountain every day where there is some pastureland, thanks to the frequent fog and higher environmental humidity. Once more, it is mainly the women and children who look after the animals because the men have gone to the cities in search of work.

The supply of drinking water to the population on the Ifni coast, which mainly depends on fishing, is guaranteed by a good network of pipelines. In contrast, the inland population exploits the argan (*Argania spinosa*) to produce oil, in women's cooperatives, or works in apiculture and in looking after livestock, basically goats (54 % according to the animal headcount, *Photo 2*). These inhabitants get water from wells at the bottom of the *uadis*, but the decrease in rainfall in the last few years (*Driouech* 2006) and the exhaustion of the wells have reduced the

*Photo 3* Erosion in Boutmezguida valley: The absence of a vegetal cover facilitates erosion; soil drags on the steep slopes and leads to poor soil conditions making it difficult for pasture to grow. / *Erosion im Boutmezguida-Tal: Das Fehlen einer geschlossenen Pflanzendecke begünstigt die Bodenerosion; der Boden rutscht an den Steilhängen ab, was zu schlechten Bodenbedingungen führt , die den Aufwuchs der Weide erschweren.*

levels and have caused a serious shortage of water for traditional activities.

## 3. Research Interest and Research Questions

Si Hmad Derham Foundation and the Geography Department at the University of La Laguna have embarked on a project to evaluate the possibility of obtaining water from the fog in two different places 30 km away from each other, with the following objectives: to repopulate the forest, to fight erosion and to support farming activities (*Photo 3*). The essential use of the water is to maintain life on the land because all the human settlements are closely tied to its presence, both on the surface and underground (*Frutos* 2006), and therefore water becomes a vitally important economic and eco-social resource. In this case, an improved availability of water would facilitate the lives of the local population, especially of the women and children who are supposed to collect the water from the wells and look after the livestock. This would also help to support rural settlements and reduce the exodus of the population to the cities, along with other initiatives that are carried out at the regional level, such as the incipient spa tourism based on the warm waters in the Anti-Atlas (*Ezaidi* et al. 2007) or the creation of women's cooperatives to harvest and manipulate argan to produce oils and cosmetics like the Inwa Nature company or the Tafyoucht Cooperative in Mesti, a village near Sidi Ifni, which both have been supported by the Si Hmad Derham Foundation.

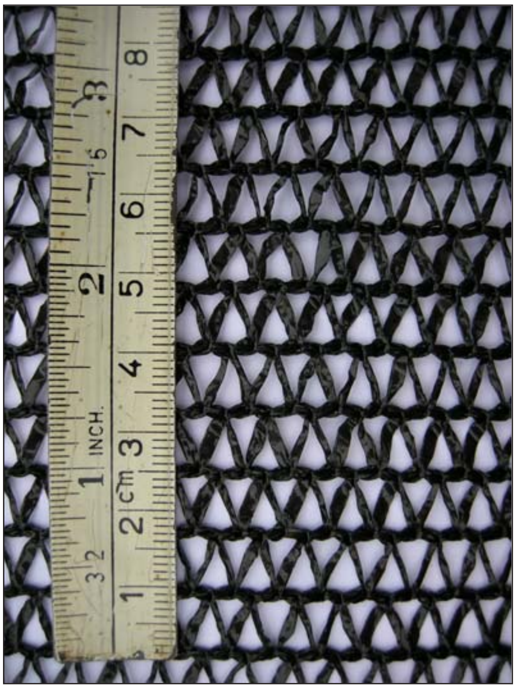

*Photo 4* Raschel type polypropylene mesh used in the study, with coverage of 45 % (single layer) / *In der Studie verwendetes Polypropylen-Netz vom Typ Raschel mit einer Abdeckung von 45 % (einlagig)*

Finally, as the aim of this research is to analyse the viability of the use of fog water as an alternative source of water to support sustainable development in the local rural communities, it was necessary to carry out a census of the population and a headcount of the livestock in the surrounding areas of Mount Boutmezguida which may benefit from using the water obtained from the screens.

## 4. Methods and Data

Four meshes of 1 $m^2$, based on the Schemenauer and Cereceda Standard Fog Collector (SFC) design model (1994a) were installed on the Ifni coast and inland to study the local cloudiness dynamics and to evaluate the efficiency of fog water collection.

The screens used consist of a metallic frame of 1 $m^2$ with a thickness of 1 cm, covered with a double layer of polypropylene mesh, Raschel-type, produced by Polysack Plastic Industries Ltd (Israel) and distributed by Polysack Europa S.L. (Barcelona, Spain). The screen is erected 2 metres above the ground, in a vertical position and perpendicular to the prevailing winds. Small droplets of water from the fog are deposited on the mesh in periods of fog, these droplets grow in size and slip down, by the force of gravity, and fall into a gutter positioned below the screen and are finally deposited in a tank on the ground. The SFCs were built at the University of La Laguna (Canary Islands). The mesh used has a coverage of 45 % when it is used in double layers and its final coverage is calculated at 60 % (*Photo 4*), with a hole size of 3 x 6 mm and an 8 years UV resistance. The local population in Ifni, who showed a lot of interest in the whole project, helped with the installation of the four SFCs.

Two local people are in charge of measuring the amount of water collected every day and assessing of whether it has rained, the condition of the sky (cloudy or clear) and the wind direction. This visual information is also compared with and complements the daily meteorological data supplied by the Meteorological Office at Sidi Ifni airport (National Meteorological Office of Morocco, 29º22' N, 10º11' W, 50 m a.s.l.), regarding the height of the cloudiness base, hours of sunshine, relative humidity, temperature and wind direction at 06, 12 and 08 hours UTC. In this phase of investigation the AVHRR (NOAA) satellite images from the Maspalomas aerospace station (Gran Canaria) and maps from the Spanish Meteorological Institute (surface area, 850 hPa, 700 hPa and 500 hPa) are only used to find out what the prevailing atmospheric situation is on the days with the greatest collection of fog water.

The fog water in this region of Morocco originates from the contact between the stratocumulus layer clouds and Ifni's mountainous surface. Fog in this region is advective clouds, formed by the atmospheric stability of the Azores anticyclone and subsidence inversion (*Marzol* 2002, 2008) that produces a loss of visibility, roughly depending on the number of droplets in the air at ground level.

Daily fog occurrence is measured visually by a local person and confirmed by the collection of water by the SFCs on the same day. So fog days are defined as days when water is measured in the SFCs. The problem is to determine the origin of the collected water – rain or fog. This has been resolved, in the statistical analysis, by eliminating the amount of water harvested by the SFCs on the days with rain (the local person reports the presence of rain through visual inspection because there isn't a rain gauge). Although the origin of the water is not important as far as the local population is concerned, it is important from a methodological perspective. In the second phase of the project an automatic weather station with a rain gauge will be installed.

## 5. Results and Interpretation

### *5.1 Wind speed and wind direction*

The role of the wind in the efficiency of fog water collection is fundamental, with regard to both wind speed and direction. Studies by *Schemenauer* and *Cereceda* (1994b), *Schemenauer* and *Joe* (1989), *Bridgman* et al. (1994) and *Marzol* (2008, in press) have shown that the optimal wind speed for collecting a good amount of water is between 3.5 and 9.0 m/s. The average wind speed on the Ifni coast is 3 m/s, with the wind accelerating at the same time as it changes direction and when it is channelled and advances towards the inland mountainous region. The dominant wind on the Atlantic coast blows from NNE or SSW but there are sharp daily variations: During the night the wind blows on 42 % of the nights from 090º to 270º (from the land to the sea), winds from 180º to 360º predominate at midday on 75 % of the days, and there is a predominance of the NNE trade winds at dusk (72 % of the days). The calms are more frequent at dawn (25 % of the days) but are drastically reduced in the course of the day (*Fig.4*).

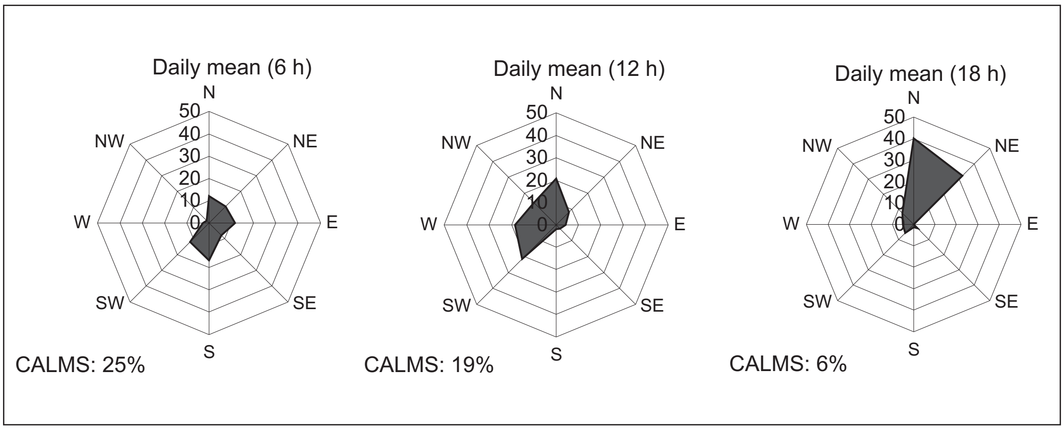


*Fig. 4* Mean frequency of wind direction at Sidi Ifni airport (60 m a.s.l.) at different times (06.00, 12.00 and 18.00 hours UTC). Data refer to 2006. / *Hauptwindrichtung am Flughafen von Sidi Ifni (60 m ü. NN) zu verschiedenen Zeiten (6, 12 und 18 Uhr koordinierter Weltzeit). Daten beziehen sich auf 2006.*

Different wind roses were drawn with data taken at 06.00 and 18.00 h UTC because according to local sources fog normally appears at these times, both in Boulaalam and Boutmezguida, with fog being more frequent in the evening:

a) fog days on the coast,
b) simultaneous fog days on the coast and inland,
c) days without fog.

There is a clear predominance of the NNE winds at dusk (18.00 hours UTC) because of the combined effects of the sea breeze, the dominant direction of the trade winds on the coast and the thermal wind driven by the temperature difference between the overheated inland desert surface and the colder ocean surface. On the other hand, a possible explanation for the predominant SW wind at 06.00 hours UTC on the days when

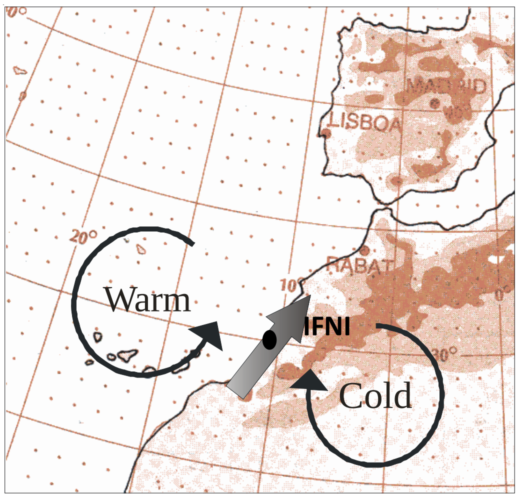


*Fig. 5* Diagram of the daily modification of wind flow patterns on the Ifni coast produced by the cooling and heating of the land surface which causes the alternation of low and high pressure areas / *Diagramm der täglichen Schwankungen der Windrichtungen an der Küste von Ifni, die durch das Abkühlen und Aufheizen der Landoberfläche hervorgerufen werden und zu wechselnden Tief- und Hochdruckgebieten führen*

fog water is collected at Boulaalam and Boutmezguida is the change in atmospheric pressure at ground level as a result of thermal change when the continent is cooler than the ocean surface; therefore, air flows from land to sea in a dominating southerly direction (*Fig. 5*).

It is not possible to analyse the role of wind speed in the fog water harvesting because the topographic conditions at Sidi Ifni airport, at 60 m a.s.l., cannot be extrapolated to the two experimental sites. It is easy to see the change in the wind direction during the day at the airport (*Fig. 6*) and that wind speed at 18.00 hours UTC (4 m/s) is double that at 06.00 hours UTC (2 m/s). After applying *Pearson's* correlation between wind speed and quantity of fog water harvested at Boulaalam the result is not significant: 0.23 at 06.00 hours and 18.00 hours UTC, and even less, 0.40 at 12.00 h.

### *5.2 The amounts of fog water collected*

The obtained results show marked differences between inland Ifni and the coast:

a) in the amount of water collected from the fog (*Tab. 2*),
b) in the most favourable orientation for optimal collection efficiency,
c) in the frequency of fog days (*Tab. 3* and *4*).

These results suggest that, firstly, Boutmezguida has a greater potential for water harvest-

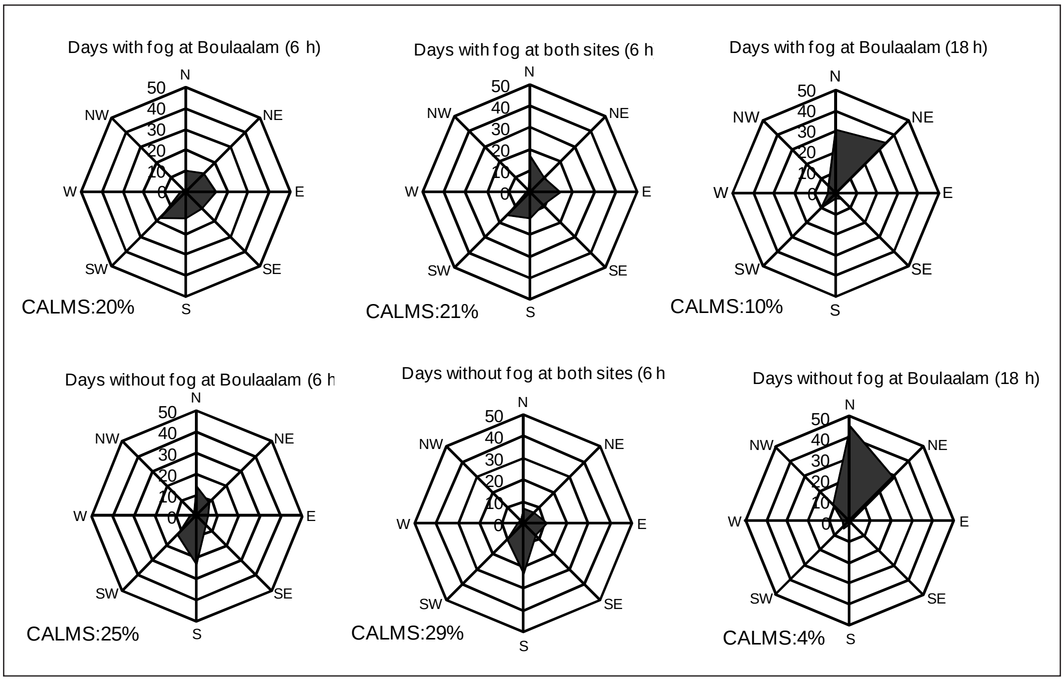


*Fig. 6* Frequencies of wind directions at Sidi Ifni airport at different times (06.00 and 18.00 hours UTC) on days with and without fog at Boulaalam and Boutmezguida. Data refer to 2006. / *Häufigkeiten der Windrichtungen am Flughafen von Sidi Ifni zu unterschiedlichen Zeiten (6 und 18 Uhr koordinierter Weltzeit) an Tagen mit und ohne Nebel in Boulaalam und Boutmezguida. Daten beziehen sich auf 2006.*

*Tab. 2* Daily mean amount of fog water at Boulaalam and Boutmezguida according to wind direction (June 2006 - December 2007) / *Tägliche Durchschnittsmenge an Nebelwasser in Boulaalam und Boutmezguida entsprechend der Windrichtung (Juni 2006 - Dezember 2006)*

| MONTH | BOULAALAM | | BOUTMEZGUIDA | |
|---|---|---|---|---|
| | Site 1 300º $l\ m^{-2}$ | Site 2 340º $l\ m^{-2}$ | Site 3 300º $l\ m^{-2}$ | Site 4 340º $l\ m^{-2}$ |
| January | 0.5 | 0.5 | 2.3 | 3.4 |
| February | 1.7 | 1.2 | 5.3 | 9.1 |
| March | 1.2 | 1.0 | 3.0 | 3.7 |
| April | 1.3 | 1.1 | 12.5 | 20.3 |
| May | 1.2 | 1.0 | 6.3 | 9.9 |
| June | 3.4 | 2.6 | 10.7 | 17.2 |
| July | 5.7 | 4.8 | 0.0 | 0.0 |
| August | 2.6 | 2.0 | 2.6 | 3.7 |
| September | 2.3 | 1.9 | 2.9 | 6.1 |
| October | 0.7 | 0.5 | 1.9 | 3.0 |
| November | 1.4 | 1.1 | 3.2 | 4.3 |
| December | 0.6 | 0.5 | 2.5 | 4.2 |
| **MEAN** | **1.9** | **1.5** | **4.4** | **7.1** |

ing than Boulaalam and, secondly, that there are local differences in the optimal orientation of the SFCs: WNW (300º) at Boulaalam and NNW (340º) at Boutmezguida.

The best average water yields are recorded at the inland sites (Boutmezguida), at site no. 3 with a WNW orientation, with 4.4 $l/m^2$/day and, above all, at site no. 4 with a NNW orientation with 7.1 $l/m^2$/day. On the other hand, the best average on the coast is at site nº 1, with a WNW orientation giving 1.9 $l/m^2$/day followed by site nº 2 with 1.5 $l/m^2$/day and a NNW orientation (*Tab. 2*). The daily average is similar.

In Boutmezguida, the largest quantity of fog water was harvested in spring whereas in Boulaalam summer yielded most fog water. An interesting point about these high values is the complete absence of water in Boutmezguida in July in both years (*Tab. 2*). This can be explained by the predominance of *Cherguis* (hot dry winds from the Sahara) and because the cloud base does not rise above 320 metres in July and sticks to the coastal mountain range as it is impossible to advance towards the interior.

The greatest daily amounts of water collected only from fog on the coast were in July 2007 with 9.8 $l/m^2$ (a monthly total of 303 $l/m^2$) whereas the largest quantity collected inland was in April 2007 (608 $l/m^2$ with a daily average of 20.3 $l/m^2$/day). The maximum daily values are 74.0 $l/m^2$ in Boutmezguida (06 June 2007) and 66.0 $l/m^2$ in Boulaalam (14 July 2007).

The third difference between both experimental sites is the frequency of fog. In spite of the fact

*Tab. 3* Monthly mean number of fog days at Boulaalam and at Boutmezguida, 2006-2007
*Durchschnittliche Zahl der Nebeltage pro Monat in Boulaalam und Boutmezguida 2006-2007*

| **MONTH** | **Number of fog days** | |
|---|---|---|
| | **Boulaalam** | **Boutmezguida** |
| January | 17 | 8 |
| February | 18 | 14 |
| March | 16 | 7 |
| April | 19 | 19 |
| May | 13 | 11 |
| June | 9 | 18 |
| July | 16 | 0 |
| August | 15 | 6 |
| September | 9 | 8 |
| October | 7 | 7 |
| November | 14 | 7 |
| December | 17 | 7 |
| **TOTAL** | **170** | **112** |

that two years is a short time to establish meteorological average values, we think that the results obtained to date suggest a clear tendency: Fog is more frequent on the coastal mountain range, with heights of about 300 m a.s.l., than in the higher inland mountains, with an elevation of more than 1,000 metres. An average of 169 fog days per year is recorded at Boulaalam whereas this figure is barely above 100 at Boutmezguida (*Tab. 3*).

There is no doubt that the frequency of fog is greater on the coast than inland, with 45 % versus 29 % of the days analysed (*Tab. 4*). However, at all times much more water is collected at the inland site than on the coast. Another remarkable feature is simultaneous fog in both places. Annual totals of 248 fog days at Boulaalam and of 139 at Boutmezguida have been reported, but only on 73 days fog occurred simultaneously at the two stations. When the cloudiness is noticeably thick and advances through the valleys towards the mountainous inland region, it is possible to record fog at both sites at the same time. Thus, on 56 % of the fog days on the coast there is also inland fog , but only on 51 % of the days with inland fog, fog is recorded simultaneously on the coast.

*Figure 7* clearly shows another differentiating feature between the two sites: There are more days of little water collection (of less than 2.0 $l/m^2$) on the Sidi Ifni coast, whereas the inland site nearly always produces more than 10.0 $l/m^2$/day (on 70 % of days) in spite of having a lower number of fog days.

In order to identify the role of rain in the water harvested in the SFCs, the number of days with rain was counted: There were a total of 12 and 18 days at Boulaalam and Boutmezguida, respective-

*Tab. 4* Monthly percentages of fog days at Boulaalam and Boutmezguida (June 2006 - November 2007)
*Anteil der Nebeltage (in %) in Boulaalam und Boutmezguida (Juni 2006 - November 2007)*

| **MONTH** | **Number of fog days per month in %** | |
|---|---|---|
| | **Boulaalam** | **Boutmezguida** |
| June 2006 | 40 | 57 |
| July | 45 | 0 |
| August | 32 | 23 |
| September | 17 | 30 |
| October | 39 | 19 |
| November | 74 | 10 |
| December | 55 | 23 |
| January 2007 | 55 | 26 |
| February | 64 | 50 |
| March | 52 | 23 |
| April | 63 | 63 |
| May | 42 | 35 |
| June | 47 | 63 |
| July | 58 | 0 |
| August | 65 | 16 |
| September | 40 | 20 |
| October | 6 | 26 |
| November | 23 | 33 |
| **MEAN** | **45** | **29** |

ly. Then, the amount of water on the rainy days was eliminated; the contribution of rainfall to the total amount of water collected by the SFCs is10 % at Boulaalam and 9 % at Boutmezguida.

The most favourable atmospheric conditions for an optimal collection of fog water exist when the stratocumulus cloud layer of the Azores anticyclone advances with the trade winds. *Figure 8* shows the meteorological map for 9th August 2006, when 66.0 l/m$^2$ were harvested at Boutmezguida but no water was harvested at Boulaalam: The centre of the Azores anticyclone lay SW of Great Britain and the isobars had a clear North-South direction between the Canary Islands and Morocco which facilitated the advance of low clouds and NNE trade winds to this latitude. On the very same day, 12.0 l/m$^2$ water were collected on the island of Tenerife, at 862 m a.s.l.

## 6. Discussion

The water needs of the inland mountain communities in Ifni are obvious. In addition, excessive pasturing and the abusive use of argan wood for fuel have caused the protective vegetal covering for the soil to disappear; as a result, the effects of

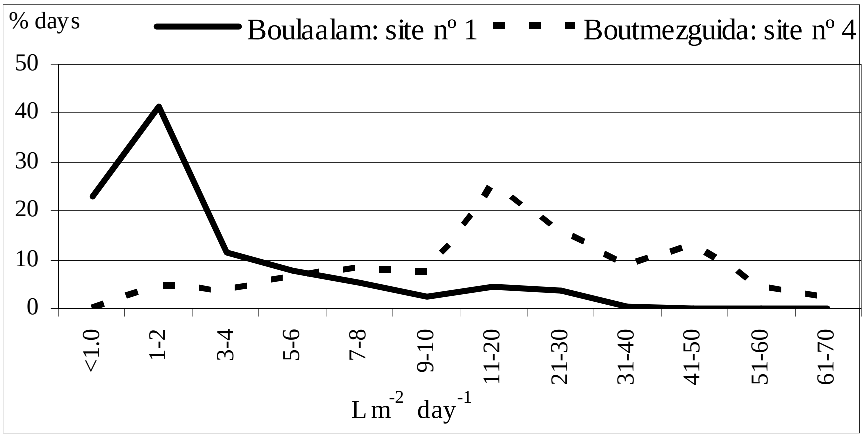


*Fig. 7* Frequency and intensity of water collected on fog days at Boulaalam and Boutmezguida
*Häufigkeit und Menge des gesammelten Wassers an Nebeltagen in Boulaalam und Boutmezguida*

erosion have increased in intensity, and the area under threat is constantly increasing. Providing water through the collection of the liquid content in the clouds is viable not only because the average amounts of water collected in the experimental phase are good, but also because inexpensive technology is used to do this and there is easy access for the local population.

The amounts of fog water collected in Morocco, in the case of Boutmezguida, can be considered as optimal and comparable with the averages

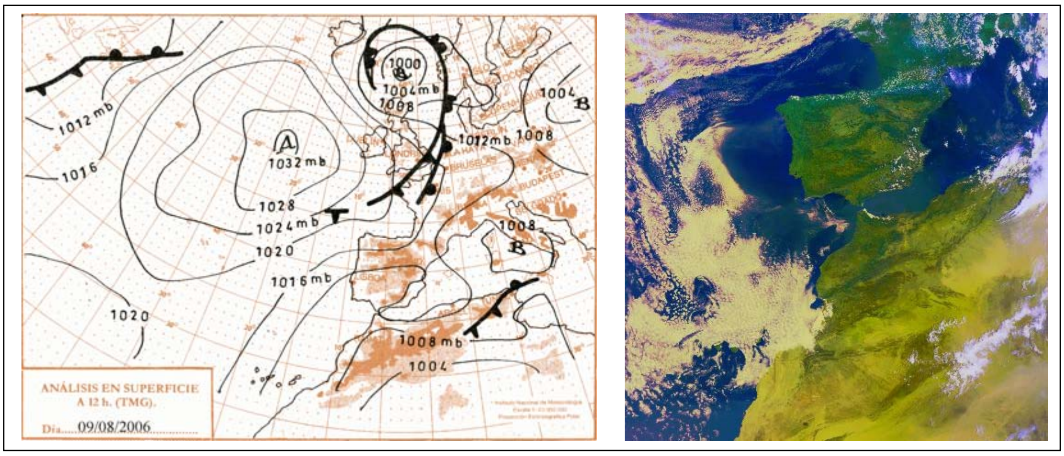


*Fig. 8* Surface map for 9th August 2006 obtained from the Spanish Meteorological Institute (left) and AVHRR (NOAA) satellite image (right) from the Maspalomas aerospace station (Gran Canaria, Spain) showing a dense cloud layer over the Ifni coast. / *Die Wetterkarte des Spanischen Meteorologischen Instituts für den 9. August 2006 (links) und das AVHRR-(NOAA)-Satellitenbild (rechts) der Bodenstation Maspalomas (Gran Canaria, Spanien) zeigen eine dichte Wolkendecke über der Küste von Ifni.*

collected in similar studies in other parts of the world (e.g. *Schemenauer* and *Cereceda* 1991; *Cereceda* and *Schemenauer* 1996; *Cereceda* et al. 1993, 1997; *Struthers* 1997; *Mundo* et al. 1998; *Prada* 2001; *Shanyengana* et al. 2002; *Rosato* and *Carter* 2006; *Olivier* and *Rautenbach* 2002, 2007; *Marzol* 2008). Values similar to those from Boutmezguida have been obtained in Cerro Orara, Peru (11º49'S; 70º09'W), in La Ventosa in Guatemala (15º29'N; 91º42'W) and Puluahua, Ecuador (0º00'; 78º30'W), or Tenerife, Canary Islands (28º32'09"N; 16º14'11"W), with quantities of water ranging between 5.3 and 12.0 l/m$^2$/day (*Fig 9*). Nearly twice as much water, 16.3 l/m$^2$/day, is collected in Bica da Cana (32º45'N; 17º03'W) in inland Madeira (Portugal) at a similar altitude as Boutmezguida and at Dhofar, Oman (17º00'N; 54º04'E) with 30.0 l/m$^2$/day during the monsoon season. Lower averages, similar to those in Boulaalam, have been found in Tofo, Chile (29º26' S; 71º15' W) with about 3.0 l/m$^2$/day, in Tshanova, South Africa (31º01' S; 17º55' E, 3 l/m$^2$/day) in Chiapas, Mexico (16º43' N; 93º17' W, 2.0 l/m$^2$/day) or in Gobabeb, Namibia (23º34' S; 15º03' E, 7 l/m$^2$/day).

## 7. Conclusions

The role of the wind direction in bringing the fog turns out to be very important, which is why it is advisable to install anemometers to determine the most favourable local orientation of the water collectors. It is also necessary to distinguish rainfall from the potential of fog harvesting in the provision of water for human use; this is why it is essential to install an automatic weather station to provide data about all meteorological parameters simultaneously.

Finally, the success of this project does not only depend on obtaining a good average collection of drinking water for the valleys, but also on the participation and collaboration of the local population which is why it is recommended to perform studies on the behaviour and per-

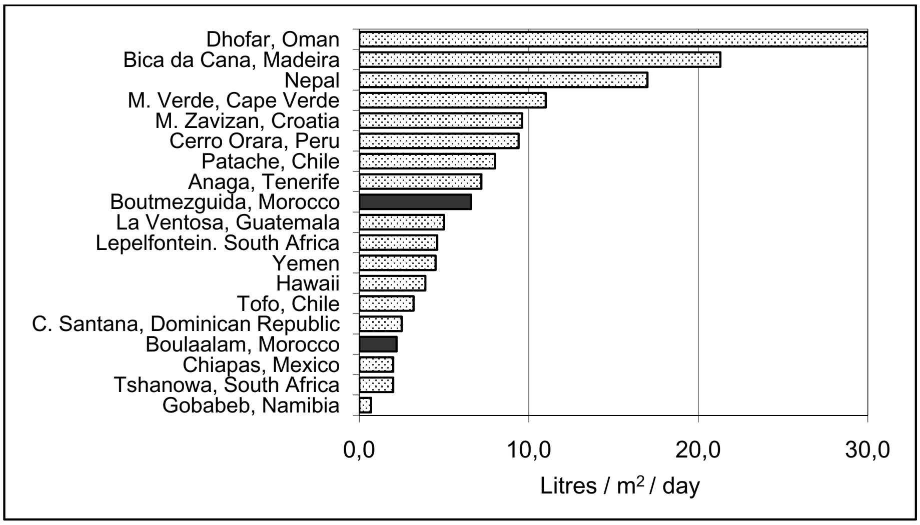


*Fig. 9* Amounts of fog water harvested in Morocco in comparison with results from other parts of the world
*Mengen des gesammelten Nebelwassers in Marokko im Vergleich mit anderen Gebieten der Welt*

ception of the local people regarding their expectations about having water available (*Cereceda* and *Schemenauer* 1993).

In spite of the short duration of the analysis (18 months) and of the fact that statistically these months were drier than normal, the evaluation of the preliminary results of this project is positive in the case of the site on Mount Boutmezguida because the water collection potential is calculated at nearly 7.1 l/m$^2$/day (*Photo 5*). The other two reasons supporting this positive evaluation and recommending progressing to the application phase are the existence of a nearby population who would benefit from this water, and the availability of large surface areas on the summits of this mountain to install large screens and the regulated water storage tanks. In addition, the accessibility to the site, for maintenance, is good.

In contrast, the prospects for fog water harvesting at Boulaalam are not so optimistic, in spite of the fact that fog is very frequent, because the average amount of water collected from the fog is less than 2.0 l/m$^2$/day. The low altitude of the Boulaalam summit is one of the main factors which limit collection efficiency. Furthermore, the use to which the collected water will be put is primarily for forestry purposes to protect the vegetal covering because water for the human population is, in fact, assured. This means that it is no longer necessary to continue the research at this site. The two SFCs in Boulaalam were taken down in January 2008 and moved to Kerdous (Tiznit), at 1,200 m a.s.l., another place where there is frequent fog and a need for fog water.

Topography and altitude prove to be the two most important local geographical conditioning factors in the cloudiness dynamics in this region of Morocco. It is safe to say that the best orientation of the fog collectors on the coast is WNW (300º) whereas in the inland mountains it is NNW (340º). The explanation for this change is that the wet air and clouds coming in from the Atlantic are channelled through the great Ifni valley and change direction as they advance towards the mountainous elevations at Boutmezguida.

There can be no doubt that the supply of water as a natural, economic, biological and social resource will positively result in a better

*Photo 5* The Boutmezguida mountain peaks, 1,225 m a.s.l., are often covered by clouds (left image) and are the most suitable sites for installing the LFCs to collect fog water for farming (right image). / *Die Berggipfel bei Boutmezguida, 1.225 m ü. NN, sind oft wolkenverhangen (links) und sind die geeignetsten Bereiche für die Installation der LFCs, um Wasser für die Landwirtschft zu gewinnen (rechts).*

quality of life for the population of the mountain valleys and may also act as an engine for sustainable development.


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*Summary: Fog Water Harvesting in Ifni, Morocco. An Assessment of Potential and Demand*

The collaboration between the Si Hmad Derhem Foundation (Morocco) and the University of La Laguna (Canary Islands, Spain) during the last two years has permitted studies on the potential of fog as a source of water in the Ifni region, situated at 29ºN on the Moroccan Atlantic coast. Two experimental sites were chosen, at different distances from the coast and at different altitudes: Boulaalam, situated at 300 m a.s.l. on a coastal mountain range, and Boutmezguida, 30 km inland and 1,225 m a.s.l. The instrument used was the Standard Fog Collector (SFC). Two SFCs were installed at each site with orientations of 300º and 340º to find out which direction harvested more fog water – to use this information at a later stage, when larger screens will be built. The aim of the study was to find out if it is viable to obtain complementary water in this arid region where rain is the only source of water and where the drought of the last few years has left the wells dry making life more difficult for the small local rural population, with a low subsistence level and an average daily consumption of 15 litres of water, with the women and children doing most of the work, looking after the animals and fetching water, because the men have gone to nearby towns in search of work. The water harvested by the screens comes from advective stratocumulus clouds carried by the trade-winds of the Azores anticyclone to the Moroccan coast which then penetrate inland until they hit the higher mountains. Significant differences between the two sites were found in the course of the research: The number of fog days is higher on the coast than inland, but less water is harvested: 2 l/m²/day on the coast versus 7 l/m²/day inland. The most favourable orientation for optimal collection is WNW on the coast whereas it is NNW in the inland mountains. There are no data that connect fog with either wind speed or rainfall, which is why it is necessary to install a weather station to collect information on these important parameters. Another difference between the two sites is the annual distribution of the fog water harvested because at Boutmezguida the yield is higher in spring and non-existent in summer, while at Boulaalam it is maximal in summer. In conclusion, we think that, at Boutmezguida, it is viable to use fog water as a supplementary resource to improve the quality of life of the people who live there.

*Zusammenfassung: Nebelwassergewinnung in Ifni, Marokko. Eine Bewertung des Potenzials und der Nachfrage*

Die Zusammenarbeit zwischen der Si Hamad Derhem Stiftung (Marokko) und der Universität La Laguna (Kanarische Inseln, Spanien) hat in den letzten zwei Jahren Untersuchungen zum Potenzial des Nebels als Wasserquelle in der Region von Ifni (an der Atlantikküste Marokkos gelegen, 29ºN) ermöglicht. Zu diesem Zweck wurden zwei Untersuchungsgebiete mit unterschiedlichen Entfernungen zur Küste und verschiedenen Höhenlagen ausgewählt: Boulaalam, in 300 m Höhe ü. NN auf einer Bergkette an der Küste gelegen, und Boutmezguida, 30 km im Landesinneren gelegen, auf 1,225 m ü. NN. Als Instrumente wurden so genannte „Standard-Nebelwasserkollektoren" (SFC) verwendet. An beiden Orten wurden jeweils zwei SFCs aufgestellt und auf 300º und 340º ausgerichtet, um festzustellen, aus welcher Richtung die größere Menge Nebelwasser gewonnen wird – um diese Information zu einem späteren Zeitpunkt zu nutzen, wenn größere Schirme aufgestellt werden können. Das Ziel dieser Studie ist es, festzustellen, ob sich auf diese Weise in diesem ariden Gebiet, in dem Regen die einzige Wasserquelle ist, wo die Dürre der letzten Jahre die Brunnen ausgetrocknet hat und das Leben der Bevölkerung erschwert hat, zusätzliches Wasser gewinnen lässt. Es handelt sich um eine kleine ländliche Bevölkerung mit niedrigem Lebensstandard und einem durchschnittlichen täglichen Wasserverbrauch von 15 Litern. Frauen und Kinder leisten den größten Teil der Arbeit, hüten das Vieh und holen Wasser, da die Männer auf der Suche nach Arbeit in die Städte der Umgebung gezogen sind. Das mit Hilfe der Schirme gewonnene Wasser stammt aus advektiven Strato-Cumuluswolken, die durch die Passatwinde aus dem Azorenhoch an die marokkanische Küste gebracht werden und landeinwärts ziehen, bis sie auf die höheren Berge stoßen. Im Verlauf der Studie wurden bedeutende Unterschiede zwischen den beiden Untersuchungsstandorten festgestellt. Die Zahl der Nebeltage ist an der Küste höher als im Landesinneren, aber es wurde weniger Wasser gewonnen: 2 l/m²/Tag an der Küste gegenüber 7 l/m²/Tag im Binnenland. Darüber hinaus wurde festgestellt, dass an der Küste WNW die günstigste Richtung für einen optimalen Wassergewinn darstellt, während landeinwärts auf den Bergen NNW optimal ist. Es liegen keine Informationen vor, inwieweit der Nebel mit der Windgeschwindigkeit oder der Regenmenge zusammenhängt. Daher besteht die Notwendigkeit, eine Wetterstation aufzustellen, um diese wichtigen Daten sammeln zu können. Ein weiterer Unterschied zwischen den beiden Untersuchungsstandorten liegt in der jährlichen Verteilung des gewonnen Nebelwassers, da die Ausbeute in Boutmezguida im Frühling größer und im Sommer gar nicht vorhanden ist, während sie in Boulaalam im Sommer am höchsten ist. Daraus schlussfolgern wir, dass es praktikabel ist, in Boutmezguida Nebelwasser als zusätzliche Wasserquelle zu verwenden, um die Lebensqualität der Bewohner in diesem Gebiet zu verbessern.

*Résumé: L'abattage de l'eau du brouillard en Ifni, le Maroc. Une evaluation du potentiel et de la demande*

La collaboration, durant ces deux dernières années, entre la fondation Si Hmad Derhem (Maroc) et l'Université de La Laguna (Îles Canaries, Espagne) nous permet de connaître le potentiel du brouillard dans la région d'Ifni, située à 29º N sur la côte atlantique marocaine. A cette fin nous choisissons deux lieux d'expérimentation situés à des distances de la côte et des altitudes différentes. L'un, Boulaalam, dans la chaîne montagneuse du littoral à 300 m d'altitude, et l'autre, Boutmezguida, à 30 km à l'intérieur des terres et à 1,225 m au-dessus du niveau de la mer. L'instrument utilisé est le Standard Fog Collector (SFC). Dans chacun des lieux choisis nous installions deux SFCs orientés à 330º et 340º afin de savoir dans quelle direction nous recueillerons le plus d'eau de brouillard – dans le but d'utiliser cette information dans la phase postérieure, lors de la construction d'écrans de plus grande taille. Le but poursuivi par cette étude est de savoir s'il est possible d'obtenir de l'eau complémentaire dans un territoire aride où l'unique source d'eau procède de la pluie et où la sécheresse de ces dernières années a séché les puits et rendu la vie de la population plus difficile. Il s'agit d'une petite population rurale, consacrée principalement à l'élevage. Les femmes et les enfants y réalisent la plupart du travail – s'occuper des animaux et aller chercher l'eau –, puisque les hommes ont émigré dans les villes les plus proches à la recherche de travail. Le niveau de subsistance est assez bas et la consommation moyenne d'eau est de 15 litres par jour et par personne. L'eau recueillie par les mailles procède des nuages stratocumulus advectifs que les vents alizés de l'anticyclone des Açores transportent jusqu'à la côte marocaine et qui, ensuite, pénètrent vers l'intérieur jusqu'à entrer en collision avec les montagnes les plus hautes. C'est un nuage transformé en brouillard quand il entre en contact avec le relief. Au cours de cette étude, d'importantes différences sont détectées entre les deux endroits. Le nombre de jours de brouillard est supérieur sur la côte qu'à l'intérieur, néanmoins moins d'eau y est recueillie : 2 $l/m^2$ /jour sur la côte face à 7 $l/m^2$/ jour à l'intérieur. L'orientation la plus favorable pour une captation optimale est celle de WNW sur la côte, alors que dans les montagnes de l'intérieur elle est de NNW. Aucune donnée ne permettant de rattacher le brouillard à la vitesse du vent et à la pluie, il est donc nécessaire d'installer une station météorologique pour nous informer de ces variables si importantes. Une autre différence entre les deux lieux est la distribution annuelle de l'eau de brouillard recueillie puisque à Boutmezguida celle-ci est plus importante au printemps et nulle en été mais à Boulaalam elle est maximale en été. En définitive, nous pensons qu'il est viable d'utiliser l'eau du brouillard à Boutmezguida comme ressource supplémentaire qui améliorera la qualité de la vie des personnes qui y vivent.

*Resumen: La extracción del agua de la niebla en Ifni, Marruecos. Una evaluación del potencial y de la demanda*

La colaboración, durante los dos últimos años, entre la Fundación Si Hmad Derhem (Marruecos) y la Universidad de La Laguna (Islas Canarias, España) permite conocer la potencialidad de la niebla en la región de Ifni, situada a 29ºN en la costa atlántica marroquí. Para ello se eligen dos lugares de experimentación a diferentes distancias de la costa y altitudes. Uno, Boulaalam, en la cadena montañosa del litoral a 300 metros, y el otro, Boutmezguida, a 30 km en el interior y 1,225 metros sobre el nivel del mar. El instrumental usado ha sido el Standard Fog Collector (SFC). En cada sitio se instalan dos SFCs con orientaciones 300º y 340º a fin de conocer con qué dirección se recolecta más agua de la niebla y ser utilizada esa información en la fase posterior, cuando se construyan pantallas de mayor tamaño. La finalidad del estudio es saber si es factible obtener agua complementaria en un territorio árido donde la única fuente de agua procede de la lluvia y la sequía de los últimos años ha secado los pozos y dificultado la vida de la población. Se trata de una pequeña población rural, con un bajo nivel de subsistencia, con un consumo medio de 15 litros de agua al día por persona y dedicada fundamentalmente a la ganadería, en la que las mujeres y los niños realizan los principales trabajos – cuidar a los animales e ir a buscar agua – porque los hombres han emigrado a las ciudades más próximas en busca de trabajo. El agua colectada por las mallas procede de la advección de las nubes estratocumuliformes que los vientos alisios del anticiclón de Azores transportan hasta la costa de Marruecos y, después, penetran hacia el interior hasta chocar con las

montañas más altas. En la investigación se detectan importantes diferencias entre los dos lugares. El número de días con niebla es superior en la costa que en el interior, sin embargo se colecta menos agua: 2 l/m$^2$/día en la costa frente a 7 l/m$^2$/día en el interior. Por otro lado, la orientación más favorable para una óptima captación es la WNW en la costa mientras que en las montañas del interior es la NNW. No hay datos que permitan relacionar la niebla con la velocidad del viento y la lluvia por lo que es necesario instalar una estación meteorológica que informe de esas variables tan importantes. Otra diferencia entre los dos lugares es la distribución anual del agua de niebla colectada porque en Boutmezguida es mayor en primavera y nula en verano pero en Boulaalam es máxima en verano. En definitiva, pensamos que es viable utilizar el agua de la niebla en el sitio de Boutmezguida como un recurso suplementario que mejorará la calidad de vida de las personas que allí viven.

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# Buchbesprechungen

**Cermak, Jan: SOFOS**. A New Satellite-Based Operational Fog Observation Scheme. – Marburg: Marburger Geographische Gesellschaft 2007. – Marburger Geographische Schriften **144**. – XIX and 132 pp., Tables, Figures, Maps, Photos. – ISBN 978-3-88353-069-7

Satellite imagery has strongly contributed to the scientific developments in the field of geography in the past decades. For example, detailed climatological information on fog and low cloud occurrence has only been made possible by the availability of the spatial coverage provided by satellites. *Jan Cermak*, who earned his Ph.D. degree with *Jörg Bendix* at Marburg, introduces the reader to this rapidly developing field of remote sensing of the Earth and contributes an essential new methodology linked to new satellite products. These latter have the potential for providing exciting new insights into the climatology of fog and low clouds. Before the launching of the new Meteosat Second Generation (MSG) weather satellites in early 2004, researchers used satellite images from the polar orbiting NOAA AVHRR satellites with a pixel resolution of roughly 1 km$^2$. This allowed for regionally resolved studies of fog distribution. The shortcoming of these satellites was that they only covered a given geographic area at very few times during the day, and the overflight times differed from day to day. Moreover, the spectral resolution of the sensors was poor which meant that fog occurrence could only be derived with sufficient accuracy from nighttime images. During daytime the problem of separation of fog from other clouds and snow (especially in mountain areas) has never been truly resolved. The MSG satellites are geostationary satellites which provide an image every 15 minutes which means that this completely new methodology could potentially help to overcome the problems associated with polar orbiting satellites. Although the 1 km$^2$ pixel resolution of an AVHRR satellite has not been arrived at yet, the MSG satellites now provide a reasonable spatial resolution that allows *Jan Cermak* to develop a suitable algorithm to retrieve fog and low