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Influence of temporal variations and climatic conditions on the physical and chemical characteristics of dew and rain in South-West Morocco

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Abstract

The physical, physico-chemical and biological characteristics of rain, fog and dew water were investigated at Mirleft in the arid coastal environment of south-west Morocco for potential use as supplementary water. The study was carried out between May 1, 2007 and Avril 30, 2008 using 4 passive dew condensers and a passive fog net collector, each with 1 m² surfaces. Collecting dew increased almost 40% the water yield although fog contributes to only 3%. Dew and rain pH were neutral and the total mineralization was considerable (dew: 560 mg/L; rain: 230 mg/L). The ions concentration agrees with the World Health Organization requirements for potable water. The biological analysis shows harmless vegetal spores and little contamination by animal/human bacteria.

1. Introduction

The application of radiative cooling during the nocturnal cycle to condense water from atmospheric vapor [1] can provide relevant solutions for arid or semi-arid countries to collect water by using a natural physical phenomenon. Radiative cooling, during the day, also limits heat in buildings.
The town of Mirleft, located in a semi-arid region in south-western Morocco (43 m asl, 29° 35' N, 10° 02' W) is characterized by low average annual rainfall (215 mm) with less than 22 rainy days per year. To face the conventional water shortage and rising water prices, the use of alternative sources of water, like dew and fog, can be envisaged. The present study aims to determine the extent to which dew and fog water can supplement or augment rainfall collection in Mirleft and whether such water is potable.

2. Measurement procedure

Four plane dew condensers (1 m²), tilted 30° from horizontal to maximize dew drop gravity flow [2], were installed on a rooftop in Mirleft as illustrated in Fig. 1a.

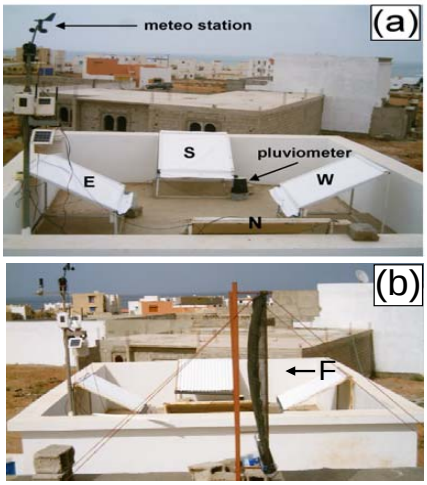

Figure 1: Measurement site located on a 3.5 m high terrace. (a) Meteorological station and 4 condensers facing north (N), east (E), south (S), west (W), with the south condenser equipped with a rain recorder. (b) Fog net collector (F) oriented east-west.

A condensing foil was used composed of material designed according to Nilsson et al. [3] (manufactured by OPUR, France, www.opur.fr). The foil is 0.35 mm thick and includes a small percentage of TiO_2 and $BaSO_4$ microspheres embedded in a matrix of low-density polyethylene (LDPE). It also contains an insoluble surfactant additive on its surface to enhance dewdrop flow. Between the foil and the condenser structure is a 2-cm thick polystyrene foam plate to provide thermal insulation. Collected water (dew and rain) by the east-, north-, west-facing condensers was measured manually every morning. Water from the south-facing condenser was recorded every 15 minutes by an automatic rain recorder. A calibration was made to properly account for the relative dew condenser/rain collecting surfaces.

In addition, a 1 m^2 fog collector oriented perpendicular to the dominant winds (east-west) was placed on a second, identical terrace within a few m from the condensers (Fig. 1b). The collector is made with two layers of polyethylene shading net (50 % transmission, ribbon width 1.7 mm).

3. Dew and rain yields

The volume corresponds to water collected through gravity flow of the drops plus the amount of the residual droplets manually scraped at the condenser surface before evaporation. During this one-year study, 178 dew events, 20 fog episodes (of which only 7 were significant) and 31 rain days were observed, corresponding to 48.8% of dew days, 2% of significant fog days and 8.5 % of rain days.

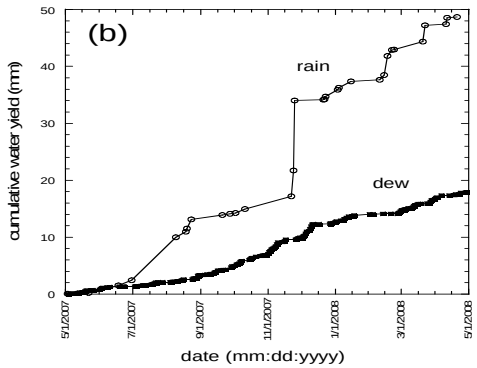

Figure 2. Cumulative dew yield (black dots, L/m^2) and rain (open circles, mm).

The cumulated amount of dew water was 18.9 mm as compared to 1.4 mm for fog water and 48.7 mm for rain water (Fig. 2). In total, the contribution of dew (and fog, although the contribution of fog is small) represents 41 % of the rain contribution and thus is significant. The dew yield was minimal in summer, in correlation with shorter night duration. The comparison of the dew yields as obtained on the 4 condensers facing north, east, south and west showed not systematic differences.

4. Physico-chemical analyses

The collection of dew and rain water was carried out from the south-facing condenser just before sunrise using sterilized polyethylene flasks. The pH and electrical conductivity (EC) measurements were performed just after water collection. Chemical and biological analyses were carried out at the National Center for Scientific and Technical Research (CNRST) in Rabat (Morocco).

The results of the analysis of the characteristic elements of dew and rain water are presented in Fig. 3. The mean dew electrical conductivity (EC) was in the order of 730 µS/cm (dew) and 316 µS/cm (rain), corresponding to a low total mineralization 0.77 EC =560 mg L^{-1} (dew) and 230 mg L^{-1} (rain). The total ions concentration averaged 534 mg L^{-1} (dew) and 287 mg L^{-1} (rain). These figures are in agreement with the EC estimation, thus showing that the chemical analysis indeed dealt with the major ions. This is also verified by the electric neutrality of cations and anions when looking at the concentrations in $mEq.L^{-1}$.

4.1 pH and EC

The dew and rain pH exhibited the same low seasonal variation, with a weak minimum during May, June, July and August (dry season). Dew pH varied between 6.75 and 7.93 and rain pH ranged between 6.49 and 7.17. Dew pH is, as usual [4], less acidic than rain because of the short time that dew is exposed to air, thus limiting the adsorption of gaseous CO_2, SO_x and NO_x. The seasonal variation of pH - lower pH when the dew yield is higher - can be explained by volume dependence.

The average values of dew and rain pH (7.4 and 6.85, respectively) are larger than the pH (5.6) of water vapour in equilibrium with atmospheric CO_2. This alkalinity is due to both the low content of sulphuric (SO_4^{2-}) and nitric (NO_3^-) acids and the large cations concentration (Ca^{2+} + Mg^{2+}) responsible for the

neutralization of these anions. The ratio (SO_4^{2-} + NO_3^-) / (Ca^{2+} + Mg^{2+}) or total acidity/total alkalinity (TA/TC), which can be regarded as an indicator of acidity, is indeed less than 1 (dew:0.4; rain:0.6).

The EC (Table 1) exhibits large fluctuations, reflecting the water mineralization variations. The dew EC ranged between 38.6 µS/cm and 2680 µS/cm, with an average value of 725 µS/cm. The rain EC varied from 14.5 µS/cm to 1081 µS/cm, with an average value of 316 µS/cm. The highest values of the dew EC were found during the dry season. Similar to the pH data, EC values decreased with increasing collected volumes, in agreement with the dissolution of particles depositing with a constant rate on the surface of the condenser. The same result was found for a study carried out in Bordeaux, France [4], Croatia [5], and in other reports concerning fog and rain in India [6,7].

Table 1: Electric conductivity (EC) (µS/cm) and total mineralization in mg/L (≈ 0.77 EC) in Mirleft as compared to other sites. (a): this study; (b): [8]; (c): [5]; (d): [9]; (e): [10]; (f) : [4].

Site	EC (µS/cm)	Total mineral (mg/L)
Mirleft (coastal, Morocco) [(a)]	725	560
Tikehau (atoll island, French Polynesia) [(b)]	580	450
Zadar (coastal, Croatia) [(c)]	204	160
Amman (near-coastal, Jordan) [(d)]	129	100
Ajaccio (island, France) [(e)]	114	88
Bordeaux (near coastal, France) [(f)]	45	35

4.2 Ionic concentrations

The mean ionic concentrations of the major chemical species obtained from the dew and rain water analyses are presented in Table 2 and Fig. 3. For both dew and rain waters, the concentration of anions are in the order $Na^+ > Ca^{2+} > Mg^{2+} > K^+$ and, for cations, $Cl^- > SO_4^{2-} > NO_3^-$. The probable source of Ca^{2+} and K^+ is from the soil, with Ca^{2+} and K^+ being suspended in the lower layer of the atmosphere and settling on the condenser surface. The presence of high concentrations of Cl^- and Na^+, and to a lesser extent Mg^{2+}, corresponds to the sea salts (the study site is within 200 m from the ocean).

Table 2. Ion concentrations for dew and rain collected from a passive dew foil condenser in Mirleft (Morocco) as compared to dew from Bordeaux (France, near the Atlantic ocean) and World Health Organization recommendations.

	Dew (Mirleft)	Rain (Mirleft)	Dew (Bordeaux)	Max WHO
pH in situ	7.4	6.85	6.26	6.5–8.5
EC (µS/cm)	725.25	316	45.1	
Ca^{2+} mg/L	48.27	32.97	1.47	
Na^+ mg/L	99.27	52.4	3.6	200
Mg^{2+} mg/L	16.19	10.81	0.36	
K^+ mg/L	9.5	5.25	0.41	
Cl^- mg/L	255.52	157.02	5.52	250
SO_4^{2-} mg/L	18.34	12.43	3.75	250
NO_3^- mg/L	14.9	11.67	2.8	50
Cu^{2+} mg/L	0.018	0.017	0.0027	2
Pb mg/L	0.005	0.006		0.01
Zn^{2+} mg/L	0.022	0.006	0.036	4
TA/TC	0.4	0.6		

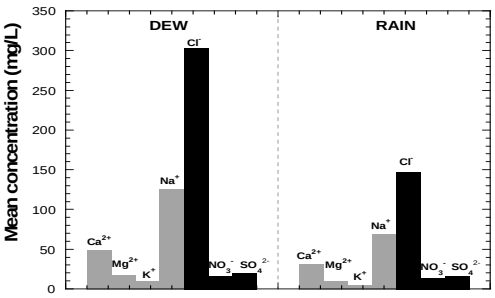

Figure 3. Mean ion concentrations for dew as compared to rain water.

The concentration of elements in dew and rain is markedly higher than in other oceanic areas such as at Bordeaux, France (see Table 2). This difference can be attributed to the strong contributions of desert particles that characterize the study area. It is noteworthy (Fig. 3) that this chemical composition is within the safety standards of the World Health Organization (WHO) for Cl^-, Mg^{2+}, and Zn.

4.4. Balance of charges

The quality of the chemical analysis can be assessed by the ion balance (sum of cations versus sum of anions). The number of charges in solution is estimated by summing the ion concentration in

mEq/L. The sum of anions and cations was well-correlated in dew and rainwater (Fig. 4) and respecting the electro-neutrality.

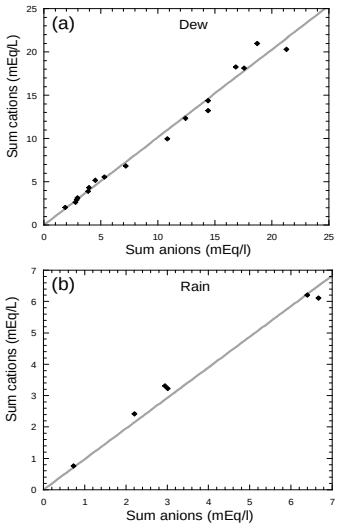

Figure 4. Correlation between total cationic and anionic charges in dew and rain water. Line: linear fit with slopes 1.01 ± 0.02 (dew) and 0.97 ± 0.03 (rain).

5. Summary and Conclusions

The annual quantity of accumulated dew corresponds to almost 40% of the yearly rain contribution. The total fog contribution remains marginal.

Dew exhibits a large mineralization, larger than rain, due to NaCl salt from marine origin and the enhanced deposition of aerosols coming from the dry, arid soil. Both dew and rain exhibit near-neutral pH. In dew are revealed the abundance of major cations Na^+ and Mg^{2+} (marine origin), and Ca^{2+} (continental origin). The acidity from dissolved CO_2, SO_x, and NO_x is mostly neutralized by Ca^{2+}, thus giving an alkaline character to both dew and rain water.

In general, dew and rain water mean characteristics are compatible with drinking standards when compared to WHO recommendations. The small content of animal and/or vegetal bacteria makes dew water potentially drinkable after a light antibacterial treatment. Then, with little investment [11], the population of the arid and semi-arid coastal areas of south-western North Africa, characterized by high air humidity and clear skies in a wide area along the coast, could make dew water a useful supplementary potable water resource.

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