

Dew and Rain Water Collection in South Croatia

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Abstract—Dew harvesting needs only weak investment and exploits a free, clean and inexhaustible energy. This study aims to measure the relative contributions of dew and rain water in the Mediterranean Dalmatian coast and islands of Croatia and determine whether dew water is potable. Two sites were chosen, an open site on the coast favourable to dew formation (Zadar) and a less favourable site in a circus of mountains in Komiža (Vis Island). Between July 1st, 2003 and October 31st, 2006, dew has been daily collected on a 1 m² tilted (30°) test dew condenser together with ordinary meteorological data (air temperature and relative humidity, cloud coverage, windspeed and direction). The mean yearly cumulative dew yields were found to be 20 mm (Zadar) and 9.3 mm (Komiža). During the dry season (May to October), monthly cumulative dew water yield can represent up to 38% of water collected by rain fall. In July 2003 and 2006, dew water represented about 120% of the monthly cumulative rain water. Dew and rain water were analyzed in Zadar. The corresponding parameters were measured: pH, electrical conductivity, major anions (HCO₃⁻, Cl⁻, SO₄²⁻, NO₃⁻, ...) and major cations (NH₄⁺, Na⁺, K⁺, Ca²⁺, Mg²⁺). Both dew and rain water are in conformity with the WHO directives for potability except Mg²⁺. Using existing roofs and refurbishing the abandoned impluviums to permit dew collection could then provide a useful supplementary amount of water, especially during the dry season.

Keywords—atmospheric water, dew chemistry, dew collection, radiative cooling, rain chemistry.

I. INTRODUCTION

THE question whether dew water can be of sufficient quantities to be useful to Man, especially by increasing dew water yield, was posed long ago. Recently, systematic investigations have been performed with respect to local meteorological parameters (wind speed, wind direction, relative humidity, etc.) [1]-[9] combining high yield radiative materials with hydrophilic properties for drop recovery using adapted condenser architecture. The maximum dew yield that was measured was in the order of 0.6 Lm⁻² [10], close to the expected maximum when accounting for the available maximum cooling radiative energy (~ 150 Wm⁻²).

The interest in such water collection devices becomes evident as the necessary cooling energy (radiative deficit) is

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free and inexhaustible. In addition, the financial investment for the collectors is small and the functioning of such condensers is preserved even if partially damaged. Special dew water condensing devices (inclined planes: see [2]; roofs: see [9], [11]) have then been built with success in Mediterranean islands (Corsica, France; Biševo, Croatia) and in India (Kothara, Gujarat). Large dew harvesting systems have been fabricated on the ground [3], [4], [12] at moderate cost. Some existing buildings – especially home roofs or rain-catching construction common in the Mediterranean basin, the so-called impluviums – present opportunities to produce dew water with only a modest financial investment for purchasing thermally insulated condensing foil (or paint) and collection gear. Such construction can capture both dew and rain (and to some extent, fog and mist).

Here we evaluate the relative contribution of both dew and rain water collection in the Adriatic area of the Mediterranean basin and their chemical quality. Dew measurements were performed from years 2003 to 2006 at two locations, in Komiža (Vis Island) and in Zadar (Dalmatian coast). This region is characterized by the presence of many very small islands that are deprived of local natural drinking water. The summer season is generally very dry and the inhabitants have built impluviums since ancient times to collect rain. Note that an early attempt to collect dew by massive condensers was carried out in the city of Vis (Vis island) during the last century [13].

The composition of dew water is determined by the dissolution of the surrounding gases and the small particles (aerosols) which settle on the surface of the condenser [14]. The quality of dew water was the object of a few studies [14]-[22]. Chemical analyses were carried out in Chile [20], in the USA [15], in Japan [17], [21], in Jordan [22], in India [23]-[24], in France [2], [4], [14], the characteristics of which can be quite different. Dew water was very corrosive in Chile with a high ionic concentration, very acidic in Japan with a high concentration of sulphates and nitrates, and only slightly alkaline and slightly mineral-bearing in Jordan and France. Biological measurements have been performed in France (Ajaccio [4] and Bordeaux [14]).

II. EXPERIMENTAL PROCEDURE

A. Measurements Sites

In Zadar, the measurement site is situated at a meteorological station operated by the Meteorological and Hydrological Institute of Croatia (MHIC), located at 44°08' N, 15°13' E, at 5 m a.s.l. It is situated on a long peninsula, spreading over the Adriatic Sea and within 10 m from the sea. The mean annual rainfall is 917 mm.

In Vis Island, the measurements were also performed at a meteorological station of the MHIC in Komiža (43°03' N, 16°06' E, at 20 m a.s.l). Komiža is a town and harbour situated in the centre of a mountainous cirque open to the sea to the SW. The Vis Island is about 140 km away from Zadar. The annual mean rainfall is 817 mm (mean computed between 2003-2005) and very erratic. Because of the situation, this site is representative of a poor location for implementing dew collection; the dew yields will thus be considered as a minimum in the area.

B. Setup

Dew was collected on a condenser of 1 m x 1 m inclined at a 30° angle from horizontal (Fig. 1). It was coated with a condensing foil, 0.35 mm thick, made of TiO₂ and BaSO₄ micro spheres embedded in low density polyethylene with one % food surfactant (similar to Nilsson [1]; made by OPUR, France, www.opur.u-bordeaux.fr). The foil was thermally insulated from the condenser frame by a 30 mm thick Styrofoam plate. Dew quantities were collected and its volume *V* measured daily in the morning, corresponding to water collected by gravity flow in a bottle and scraped from the surface. As polyethylene is sensitive to UV radiations, the foils was changed every six months. The following parameters were also recorded: air temperature, relative humidity, wind speed at 10 m elevation, wind direction, cloud cover data *N*. These parameters were recorded at the following times (UTC +1) 08:00, 19:00, 21:00. Frost were excluded from the dataset. In Zadar, a cup anemometer measures the windspeed at 10 m height, with a stalling speed of 0.5 m/s and within 0.1 m/s resolution. In Biševo, windspeed is measured in Beaufort (Bf). Rain was collected and its volume measured in a standard stainless steel 200 cm² surface area pluviometer.



Fig. 1. The dew condenser (1m x 1m surface area) at the Zadar station (Croatia). Collection is made in a PE bottle (B)

Dew and rain water were stored in Polyethylene bottle of 0.5 L. Water was not filtered. Volumes below 10 cm³ were discarded as this amount is the minimum needed for complete chemical analysis. The dew and rain samples are sent to the chemical laboratory in Zagreb each two weeks; meanwhile, the samples are stored in a refrigerator. The following determinations were performed (i) physico-chemical properties: pH, conductivity EC. (ii) chemical concentration; cations: NH₄⁺, Na⁺, K⁺, Ca²⁺, Mg²⁺, anions: HCO₃⁻, Cl⁻, SO₄²⁻, NO₃⁻; (iii) Determinations specific to potable water.

III. RESULTS AND DISCUSSIONS

A. Dew Yield

The dew yield data are shown in Figs. 2ab (evolution) and the statistics are summarized in Table I. The mean yearly dew yield is 19.9 mm (Zadar) and 9.3 mm (Komiža). The daily dew yields can exceed 0.4 mm on both locations and sometimes reach 0.6 mm in Komiža. Zadar has more dew days (18%) than Komiža and the cumulative dew yield is about 2.5 times that of Komiža. The reasons are twofold. (i) Due to this coastal setting, the Zadar mean windspeed is lower than in Komiža (Zadar : 2.5 m/s ± 2, Komiža: 2.3 Bf ± 1, (ii). The location of Komiža, with strong infrared scattering from the mountains around, hinders dew formation. However, although the number of dew days is fewer than in Zadar, the dew yields are higher on average. This observation agrees with a comparison between island and coastal (and continental Alpine sites), see Beysens et al. [6].

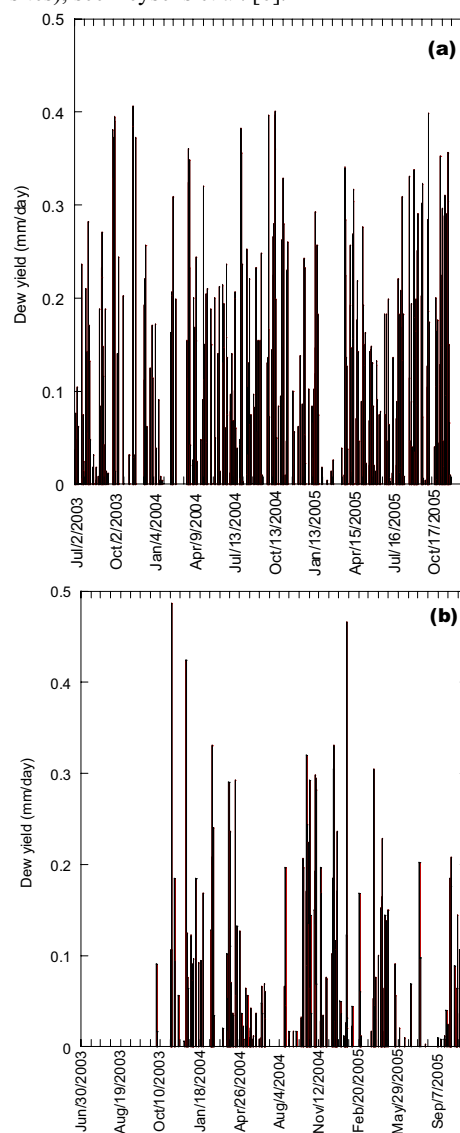


Fig. 2 Evolution of dew yields (in mm/day) for both experimented sites (2 ½ year period). (a) : Zadar, (b) : Komiža

TABLE I
 STATISTICS OF DEW EVENTS AND DEW YIELD

		Zadar	Komiza
Experimental period (mm/dd/yyyy)		07/01/2003 - 12/31/2005	07/01/2003 - 10/31/2005
Dew days		349 (39.1%)	184 (20.6%)
Yields (mm/day)	Minimum	0.002	0.002
	Maximum	0.406	0.486
	Mean	0.138	0.108
Cumulative (mm)	Cumulative	48.252	19.898
	Cumul partial year 2003	8.535	2.464
	Cumul year 2004	19.029	10.366
	Cumul year 2005	20.688	7.068

B. Dew and Rain Contributions

In order to assess the benefit of dew water collection in addition to rainwater, monthly dew yields (mm/month) are compared to monthly rainfall (mm/month). Fig. 4 compares the dew contribution with respect to rain (in %). In the summer months (July and August), dew water contribution is important, especially in Zadar with 34% and 38%, respectively, in 2004. In both July 2003 and 2006, the ratio in Zadar was about 120%, during a period where an important rainfall deficit occurred in Europe. For the whole period, dew represents 11.7% of rainfall, with a monthly variability of 26.5% of the water balance in Zadar and 1.6%, with a monthly variability of 3.1% in Komiza. It is interesting to note that, even in drought conditions such as during summer 2003, dew continues to provide a consistent (and sometimes only available) amount of water. Low-cost modifications of thermal and wetting properties of already existing roofs, such as in the neighboring island of Biševo (see [11]), or the coating of existing rain collectors (impluviums) that need only a moderate investment, represent obvious opportunities to augment water supply.

IV. PHYSICO-CHEMICAL ANALYSIS

A. General

The statistical analysis of the elements characteristic of dew and rain water is presented in Tables II & III. The physicochemical analysis shows that the nature of this water is alkaline and average conductivity does not exceed 200 $\mu\text{S}/\text{cm}$. The concentration of the various ions show that the sum of the cations is higher than the sum of the anions.

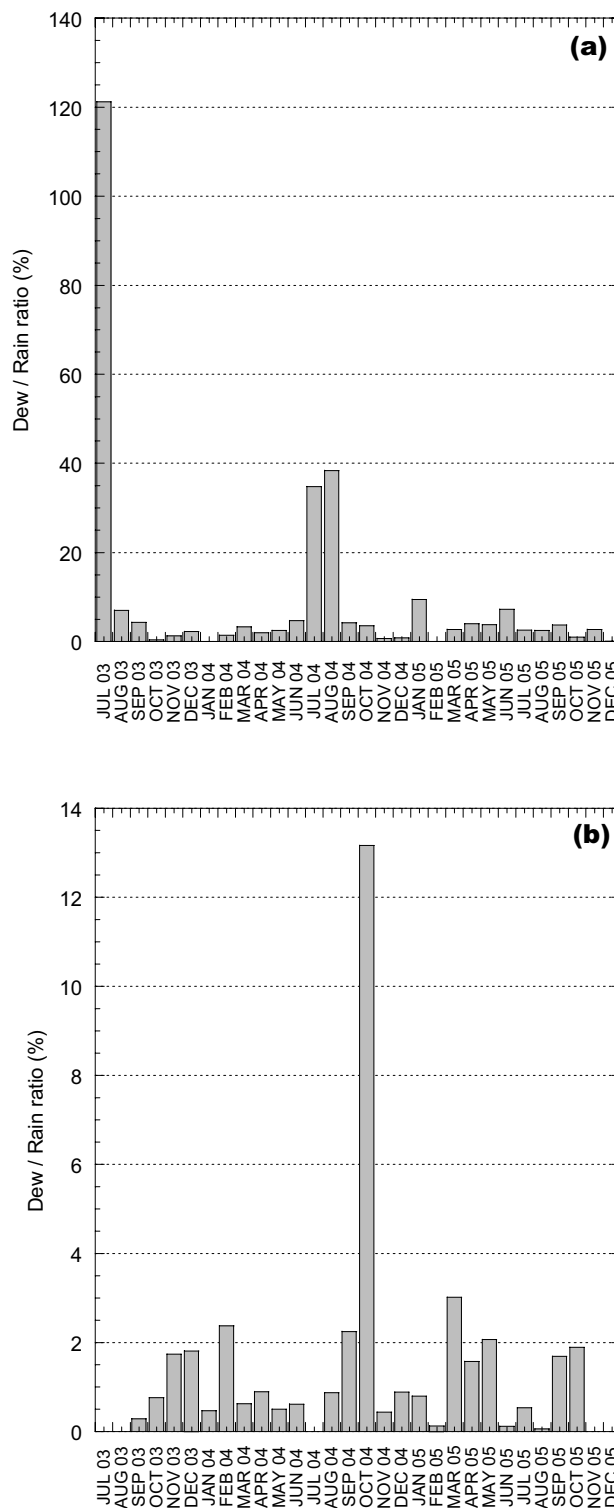


Fig. 4 Monthly contribution (%) dew yield (mm/month) compared to rain (mm/month) (%). (a) Zadar; (b) Komiza

TABLE II
VARIOUS PHYSICO-CHEMICAL PROPERTIES OF DEW WATER BETWEEN YEARS
2004 AND 2006

Dew : 373 events between 2004 and									
Measurements	2004 (34.85%)			2005 (31.37%)			2006 (33.78%)		
	Moy	Min	Max	Moy	Min	Max	Moy	Min	Max
pH	6.93	5.69	7.78	6.62	5.45	7.78	6.58	5.53	7.57
EC(μ S/cm)	216.48	41	1117	195.66	23	1861	174.31	19	719
Ca ⁺⁺ mEq/L	2.11	0.08	9.7	1.79	0.17	7.49	1.25	0.12	6.7
Na ⁺ mEq/L	0.42	0.00087	10.55	0.22	0.025	0.99	0.3	0.03	1.64
Mg ⁺⁺ mEq/L	0.35	0.0016	14.52	0.14	0.014	0.56	0.2	0.002	2.66
K ⁺ mEq/L	0.054	0.0019	1.25	0.073	0.004	1.16	0.05	0.004	0.20
NH ₄ ⁺ mEq/L	0.036	0	0.18	0.017	0	0.026	0.1	0	1.4
H ⁺ mEq/L	0.0002	<10 ⁻⁴	0.002	0.0004	<10 ⁻⁴	0.0035	0.0004	<10 ⁻⁴	0.003
Cl ⁻ mEq/L	1.35	0.025	73.8	0.27	0.042	1.22	0.35	0.049	1.6
SO ₄ ⁻ mEq/L	0.11	0	2.34	0.066	0.0091	0.25	0.07	0.013	0.45
NO ₃ ⁻ mEq/L	0.015	0	0.092	0.0093	0	0.062	0.01	0	0.1
HCO ₃ ⁻ mEq/L	0.0065	0.0025	0.31	0.038	0.0014	0.31	0.032	0.001	0.19

TABLE III
VARIOUS PHYSICO-CHEMICAL PROPERTIES OF RAIN WATER
BETWEEN YEARS 2004 AND 2006

Rain: 276 events between 2004 and									
Measurements	2004 (40.58%)			2005 (35.14%)			2006 (24.28%)		
	Moy	Min	Max	Moy	Min	Max	Moy	Min	Max
pH	6.37	4.33	7.99	6.5	4.24	8.67	6.13	4.51	7.76
EC(μ S/cm)	182.19	8	4850	228.53	6	4980	123.6	9	2211
Na ⁺ mEq/L	0.92	0.009	35.62	1.001	0.004	21.78	0.65	0.025	19.26
Ca ⁺⁺ mEq/L	0.52	0.024	4.71	0.83	0	12.09	0.25	0.054	1.52
Mg ⁺⁺ mEq/L	0.29	0	11.66	0.4	0.007	7.32	0.27	0.029	4.3
NH ₄ ⁺ mEq/L	0.027	0	0.58	0.019	0.0001	0.15	0.021	0	0.1
K ⁺ mEq/L	0.026	0.0006	0.8	0.025	0.0007	0.4	0.02	0.002	0.4
H ⁺ mEq/L	0.0028	<10 ⁻⁵	0.046	0.0023	0	0.057	0.0028	<10 ⁻⁵	0.031
Cl ⁻ mEq/L	0.94	0.015	34.86	1.57	0.0054	44.62	0.83	0.025	20.54
SO ₄ ⁻ mEq/L	0.061	0.004	1.36	0.12	0.0013	3.74	0.038	0.0003	0.72
HCO ₃ ⁻ mEq/L	0.05	0.0001	0.5	0.113	0.0001	2.4	0.026	0.0001	0.29
NO ₃ ⁻ mEq/L	0.015	0.0016	0.095	0.013	0.0004	0.12	0.012	0.0007	0.046

B. pH

The evolution of pH for dew and rain is presented in Fig. 5. For both dew and rain, a seasonal variation is observed with a bump in summer. The dew pH ranges between 6 and 7.5, with a mean value of 6.71 and the rain pH between 5.3 and 7.3, with a mean value of 6.33. The seasonal variation (pH is larger in summer) can be attributed to the difference in quantity of water collected for each season, the lower volumes in summer showing a higher pH (Fig. 5). The pH of rain is in average slightly more acidic than dew's, by about 0.4 pH unit. This difference between dew and rain pH is attributed to (i) the differences in the atmospheric composition in aerosols and gas at high elevation (cloud) and low elevation (dew) [22], [25] and (ii) the time where the rain and dew droplets are exposed to the environment [14].

The season dependence is firstly due to the variation of the pH with respect to the collected volume, with the highest value for the lowest volume (Fig. 6). The sample volume is indeed proportional to the dew duration time dt , which obviously varies with season (Fig.5). This dt dependence can be understood as follows. The rate of deposition of alkaline soil derivative dust can be reasonably assumed to be constant in time. Dew water dissolves first the deposited aerosols then those that continue to drop. Thus the higher V (and duration time dt), the more diluted are the alkaline species in the sample. Concerning acidic gaseous precursors NO_x, SO_x and HCl, their concentration in the sample will be proportional to their atmospheric concentration as the result of the dissolution in aqueous phase equilibrium. Accordingly, acidity neutralization is lowered with sample volume augmentation.

pH shows an attenuation of extreme values and neutralization tending to pH = 5.6, the pH at which dissolved CO₂ is equilibrated with atmospheric CO₂ in normal conditions.

This volume dependence, however, cannot explain the pH variations being related to only the concentration of gas and solid particles adsorbates [14]. Indeed, the seasonal variation of rain pH is the same as dew variation, which means that volume cannot be the only variable.

The above general behaviors can be explained by the different nature of water acidity for dew and rain. Dew acidity comes from CO₂ absorption and acidic aerosols dissolution during droplet growth. It depends on the condensed volume or condensation time that influences soil dust dilution (major alkaline species), as discussed previously. The pH distribution spreads from about 7 for small volumes and then short dt (Fig. 6) to 5.5 for long dt . For high volumes, the contact time of CO₂ and acidic gases is higher, solid alkaline species are more diluted and then dew is more acidic.

For rain, CO₂ is well mixed in cloud droplets, closer to the equilibrium assumed to be pH = 5.6 in current conditions. Consequently, the pH tends to be more acidic. A large distribution is due to the various quantities of acidic species (SO₂, NO_x) or alkaline soil dust adsorbed by water during atmosphere over crossing. These various atmosphere compositions are influenced by human activities, such as fluctuating pollutant production and wind dispersion, or precedent rain events that clean aerosols before the measurement [23].

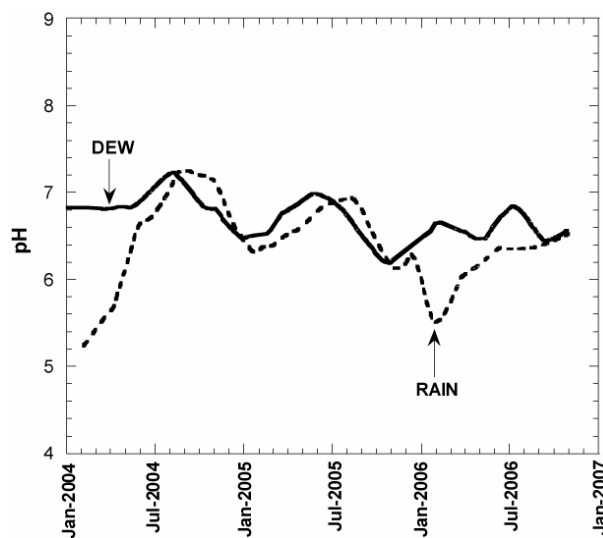


Fig. 5 Dew and rain pH evolution for years 2004 – 2006

C. Electric Conductivity

The electric conductivity EC of dew for all the period takes values from 19 μ S/cm to 1117 μ S/cm with an average of 191,09 μ S/cm and a standard deviation of 174,04 μ S/cm. These values are comparable to the conductivity of rain whose EC values extend from 6 μ S/cm to 1591 μ S/cm and mean EC = 132,47 μ S/cm, with a standard deviation of 214,35 μ S/cm. The mean values are somewhat smaller than the standard value (400 μ S/cm at 20°C) for potable water as requested by the European Commission [26]. One notices in this study that

the dew conductivity presents seasonal variations more important than those observed with rain, the largest values being in June and July and June (Fig. 7). Alike pH, the electric conductivity decreases with largest volumes, in agreement with the dissolution of gases and particles deposited on the condenser surface (Fig. 8). The same observation was made in a study carried out in Bordeaux [14] and in other reports concerning fog and rain in India [23], [24].

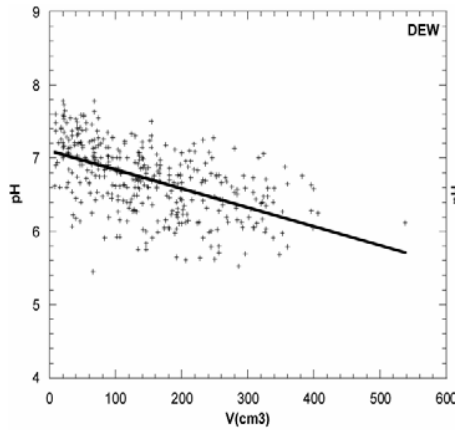


Fig. 6 Rain and dew pH variation with respect to the sample volume

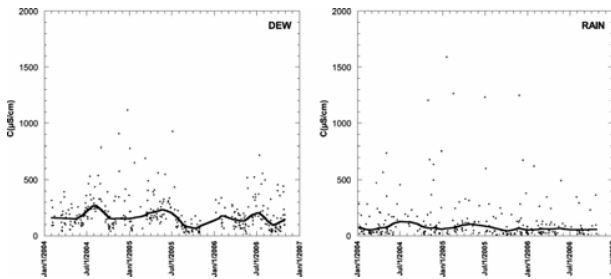


Fig. 7 Evolution of the electric conductivity

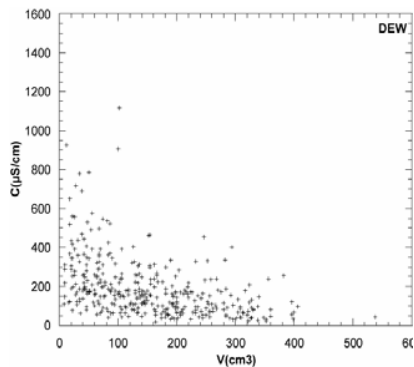


Fig. 8 Influence of the sampling volume on the electric conductivity

D. Ionic Concentration

The average ionic concentrations (in mEq/L) of the major chemical species as obtained from the analysis dew and rain water for the three years of study are presented in Fig. 9. In dew water, the cations concentrate in different ways. For years 2004 and 2005, $Ca^{2+} > Na^+ > Mg^{2+} > K^+ > NH_4^+$,

whereas during year 2006, $NH_4^+ > K^+$. The concentration of anions follows the same evolution, with $Cl^- > SO_4^{2-} > HCO_3^- > NO_3^-$, except in 2006 where $NO_3^- > HCO_3^-$. Concerning rainwater, the concentration of ions is different from what is observed in dew. For cations, one observes:

- year 2004, $Na^+ > Ca^{2+} > Mg^{2+} > NH_4^+ > K^+$
- year 2005, $Na^+ > Ca^{2+} > Mg^{2+} > K^+ > NH_4^+$
- year 2006 $Na^+ > Mg^{2+} > Ca^{2+} > K^+ > NH_4^+$

In contrast, the anions evolve/move in the same way for all the period of study, $Cl^- > SO_4^{2-} > HCO_3^- > NO_3^-$.

The sources of Ca^{2+} , Mg^{2+} , K^+ are aerosols, that is dust coming from the soil that are suspended in the lower layer of the atmosphere and brought to the surface of the condenser by the wind. The high presence of Cl^- and Na^+ is mainly due to the sea salts that are convected in the neighbourhoods of the sites of study. These aerosols modify the pH (5.6) of water vapour in equilibrium with atmospheric CO_2 , as shown by the mean pH for dew and rain water, respectively 6.7 and 6.35 > 5.6. This alkalinity is due to the low content of sulphuric acid (SO_4) and nitric acid (NO_3) and the large cation concentrations ($\sum cations > \sum anions$) responsible for the neutralization of these anions. Thus the ratio: $(SO_4 + NO_3) / (Ca^{2+} + Mg^{2+})$, or total acidity/ total alkalinity TA/TC, can be regarded as an indicator of acidity. A ratio TA/TC < 1 indicates the alkaline nature of water and if TA/TC > 1, it indicates the presence of free anions responsible for a weak pH (Table IV). The comparison of the ionic composition of dew and rain water shows that dew is richer in Ca^{2+} , K^+ et SO_4 than rain where Na^+ , Mg^{2+} and Cl^- are dominant (Fig. 7).

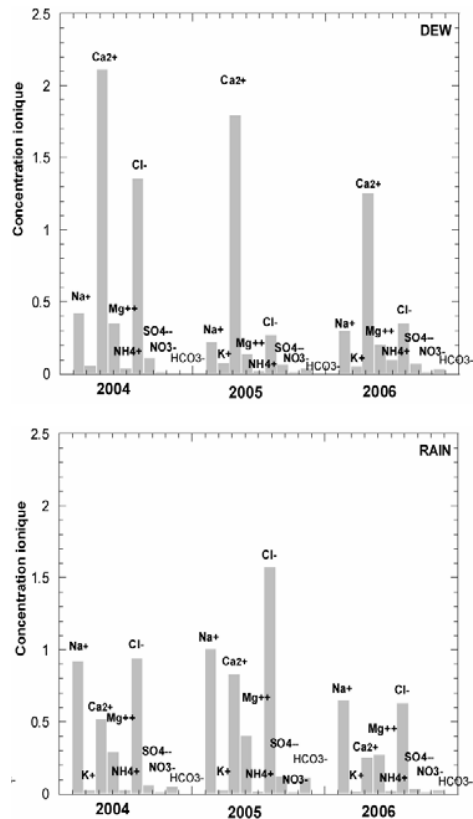


Fig. 9. Concentration (mEq/L) of different ions in dew and rain water

TABLE IV
COMPOSITION OF DEW WATER IN ZADAR (CROATIA) AS COMPARED TO RAIN WATER AT THE SAME LOCATION, TO WHO REQUIREMENTS AND TO A LOW MINERALIZED SPRING WATER (MONT ROUCOUS, FRANCE)

	Rosée (2004-2006)	Pluie (2004-2006)	Max WHO	Mt. Roucoux
	Moy	Moy		
pH	6,7	6,35	9,5	6
EC(µS/cm)	195,59	194,25		<24
Ca++ mg/L	34,7	10,93		1,2
H+ mg/L	0,00035	0,0027		
K+ mg/L	2,3	3,87		0,4
Mg++ mg/L	2,84	3,87	0,5	0,2
Na+ mg/L	13,18	20,16	200	280
NH4+ mg/L	0,9	0,42		
Cl- mg/L	23,7	38,53	250	3,2
HCO3- mg/L	2,75	4,02		
NO3- mg/L	0,71	0,83	40	2,3
SO4- mg/L	3,88	3,66	500	3,3
TATC	0,05	0,1		

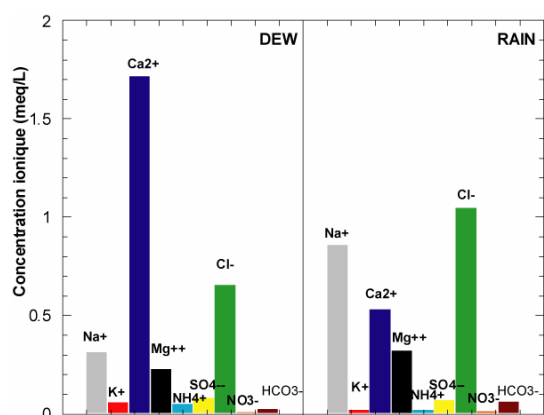


Fig. 10 Comparison between dew and water ion concentration

E. Marine Contribution

In order to estimate the contribution of the different ions constituting dew and rain water, the sea-salt fraction, SSF, was calculated. The other species are expressed to be as no sea origin (no sea-salt fraction NSSF). The totality of Na⁺ considered of sea origin is the principal reference of the present calculation [27]-[29] as well as the ionic concentration of sea water given by Riley and Chester [30]. The parameters SSF and NSSF are described by the following equations:

$$\%(SSF)_X = 100 \times \frac{[Na][X]}{[Na]_X} \quad (1)$$

$$\%(NSSF)_X = 100 - \%(SSF)_X \quad (2)$$

where X is the component whose origin has to be determined. The results presented in Table V show that in dew Ca²⁺, K⁺, SO₄²⁻ and NO₃⁻ (83.3 % of the total ions) are not of sea origin; Mg²⁺ seems affected by the particles of the marine salt as well as the Cl⁻ whose %SSF is equal to 54,76. In contrast, in rain water, the high NSSF of Ca²⁺ and NO₃⁻ indicate that they are not influenced by sea, whereas the other ions shows a strong sea contribution, especially for Cl⁻.

F. Neutralisation factor

The acid substances (SO₄²⁻, NO₃⁻) contained in dew and rain water react with the basic components (Ca²⁺, Mg²⁺, NH₄⁺, K⁺). During this reaction, acidity disappears and water becomes

TABLE V
COMPARISON OF THE RATIO %(SSF)_X AND %(NSSF)_X FOR DEW, RAIN AND SEA WATER

Ions	Sea water ratio	Dew ratios	Rain ratios	Dew %SSF	Dew %NSSF	Rain %SSF	Rain %NSSF
Ca++ mEq/L	0.044	5.5484	0.61628	0.79302	99.20698	7.1396	92.86
Mg++ mEq/L	0.227	0.74194	0.37209	30.59565	69.40435	61.006	38.994
K+ mEq/L	0.022	0.19032	0.027907	11.55932	88.44067	78.833	21.167
Cl- mEq/L	1.166	2.129	1.2209	54.76666	45.23334	95.501	4.499
SO4- mEq/L	0.04	0.26452	0.084884	15.12195	84.87805	47.123	52.877
NO3- mEq/L	0.00002	0.035484	0.015116	0.05636	99.94363	0.13231	99.868

neutral. In order to determine the part played by the cations to neutralize sulphuric and nitric acids, a factor of neutralization (NF) can be calculated according to the following formula (Das et al., 2005):

$$NF_X = [X] / [NO_3^- + SO_4^{2-}] \quad (3)$$

where X is the species responsible for neutralization (Table VI). The important Ca concentration compared with the other ions in dew and rain water implies that the more neutralizing cation is Ca²⁺, which shows the highest NF, followed by Mg²⁺, K⁺ and NH₄⁺. The dew NFs are higher than those of rain, this is presumably because dew forms near the ground, collecting more neutralizing particles (Ca²⁺, Mg²⁺) than water that forms in higher elevation.

TABLE VI
NEUTRALISATION FACTOR FOR SOME CATIONS

Ions	Dew	Rain	Dew NF	Rain NF
K+ mEq/L	0.059	0.024	0.63441	0.27907
Ca++ mEq/L	1.72	0.53	18.49462	6.16279
Mg++ mEq/L	0.23	0.32	2.47312	3.72093
NH4++ mEq/L	0.051	0.022	0.54839	0.25581

V. CONCLUSION

Passive dew harvesting requires a small financial investment but can exploit a free, inexhaustible and environmental friendly water source. In the Mediterranean Dalmatian area, it can serve as a useful complementary source of water when other sources are lacking. The two sites investigated here, Zadar on the coast and Komiža in the Vis island, provide an overview of the range of dew water production that can be obtained from an unfavorable site (Komiža, 9.3 mm/y) and a more favorable one (Zadar, 20 mm/y). In the summer dry season (May – October), the monthly contribution of dew water compared to rainfall is on order of 38% (July 2004) and has reached 120% (Summers 2003 and 2006). Refurbishing abandoned traditional rain collectors (impluviums), which are numerous in the Dalmatian area, is a viable option to collect rain and dew water. For example, the impluvium at Podšpilje near Komiža, with a moderate surface area of 1300 m², could provide about 17 m³ supplementary water per year, a useful supplementary amount especially during the dry summer season when rainfall is lacking.

Concerning the chemical quality of dew, during the period of study (3 years), the mean pH of dew of rain was

respectively 6,7 and 6,35. The chemical composition reveals in both dew and rain the importance of cations Ca^{2+} , Na^+ , Mg^{2+} and anion Cl^- for the anions. The high percentage of SO_4^{2-} with respect to NO_3^- suggests that the former is mostly responsible for lowering the pH. This acidity is neutralized firstly by Ca^{2+} , whose factor of neutralization is the largest when compared to Mg^{2+} and K^+ . The calculation of the fraction of sea salt shows that, rather surprisingly, most of ions in dew are not influenced by the sea vicinity, except Cl^- . For rain water, the marine contribution is important for ions Cl^- , K^+ and Mg^{2+} .

Both dew and rain water meets in average the WHO requirements for potable water, except for Mg^{2+} whose concentration is about 6 times larger the maximum value (0.5 g/L). However, dew and rain can be still considered as potable when regarded as a spring water.

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REFERENCES

- [1] T. Nilsson, W.E. Vargas, G.A. Niklasson, C.G. Granqvist, Condensation of water by radiative cooling. *Solar Energy*, 1994, 5, 310–317.
- [2] M. Muselli, D. Beysens, J. Marcillat, I. Milimouk, T. Nilsson, A. Louche, Dew water collector for potable water in Ajaccio (Corsica island, France). *Atmospheric Research*, 2002, 64, 297–3.
- [3] M. Muselli, D. Beysens, I. Milimouk, A comparative study of two large radiative dew water condensers. *Journal of Arid Environments*, 2006a, 64, 54–76.
- [4] M. Muselli, D. Beysens, E. Soyeux, Chemical composition of dew water from passive radiative condenser in Corsica Island (France). *Journal of Environmental Quality*, 2006b, 35, 1812–1817.
- [5] D. Beysens, I. Milimouk, V. Nikolayev, M. Muselli, J. Marcillat, Using radiative cooling to condense atmospheric vapor: a study to improve water yield. *Journal of Hydrology*, 2003, 276, 1–11.
- [6] D. Beysens, M. Muselli, V. Nikolayev, R. Narhe, I. Milimouk, Measurement and modelling of dew in island coastal and alpine areas. *Atmospheric Research*, 2005a, 73 (1/2), 1–22.
- [7] A.F.G. Jacobs, B.G. Heusinkveld, S.M. Berkowicz, Passive dew collection in a grassland area, The Netherlands. *Atmospheric Research*, 2008, 87, 377–385.
- [8] G. Sharan, H. Prakash, Dew condensation on a greenhouse roof at Kothara, *Journal of Agricultural Engineering*, 2003, 40(4), 75–76.
- [9] G. Sharan, D. Beysens, I. Milimouk, A study of dew water yields on a galvanized iron roof in Kothara (North-West India). *Journal of Arid Environments*, 2007, 69, 259–269.
- [10] S. Berkowicz, D. Beysens, I. Milimouk, Heusinkveld, M. Muselli, E. Wakshal, A. Jacobs, Urban dew collection under semi-arid conditions: Jerusalem. *Proc. Third International Conference on Fog, Fog Collection and Dew*, Cape Town, South Africa, October 11–15, 2004. Paper E4.
- [11] D. Beysens, O. Clus, M. Mileta, I. Milimouk, M. Muselli, V.S. Nikolayev, "Collecting dew as a water source on small islands: the dew equipment for water project in Bisevo (Croatia)" *Energy* 32, pp. 1032–1037 (2007).
- [12] G. Sharan, Dew Harvest to Supplement Drinking Water Sources in the Arid Coastal Belt of Kutch. Centre for Environmental Education, India, 2006.
- [13] W. Klaphake, 1936. Practical methods for condensation of water from the atmosphere, *Proc. Society of Chemical Industry of Victoria*, 36, 1102.
- [14] D. Beysens, C. Ohayon, M. Muselli, O. Clus, Chemical and biological characteristics of dew and rain water in an urban coastal area (Bordeaux, France). *Atmospheric Environment* 40, 2006, 3710–3723.
- [15] W.R. Pierson, W.W. Brachaczek, Dew chemistry and acid deposition in Glendora, California, during the 1986 Carbonaceous species methods comparison study. *Aerosol Science and Technology*, 1990, 12:8–27.
- [16] P.A. Mulawa, S.H. Cadle, F. Lipari, C.C. Ang and R.T. Vandervennet, Urban dew: Its composition and influence on dry deposition rates. *Atmospheric Environment*, 1986, 20:1389–1396.
- [17] H. Okochi, T. Kajimoto, Y. Arai, M. Igawa, Effect of acid deposition on urban dew chemistry in Yokohama, Japan. *Bulletin of the Chemical Society of Japan*, 1996, 69:3355–3365.
- [18] W.R. Pierson, W.W. Brachaczek, R.A. Gorse, S.M. Japar, J.M. Norbeck, On the acidity of dew. *Journal of Geophysical Research*, 1986, 91, D3: 4083–4096.
- [19] E. Sceller, Amino-acids in dew – origin and seasonal variation. *Atmospheric Environment*, 2003, 35, 2179–2192.
- [20] M.A. Rubio, E. Lissi, G. Villena, Nitrite in rain and dew in Santiago City, Chile. Its possible impact on the early morning starts of the photochemical smog. *Atmospheric Environment*, 2002, 36:293–297.
- [21] M. Chiwa, N. Oshiro, T. Miyake, N. Nakatani, N. Kimura, T. Yuhara, N. Hashimoto, H. Sakugawa, Dry deposition washoff and dew on the surfaces of pine foliage on the urban- and mountain-facing sides of Mt. Gokurakuji, western Japan. *Atmospheric Environment*, 2003, 37, 327–33.
- [22] A. Jiries, Chemical composition of dew in Amman. *Atmospheric Research*, 2001, 37:261–268.
- [23] K. Ali, G.A. Momin, S. Tiwari, P.D. Safai, D.M. Chate, P.S.P. Rao, Fog and precipitation chemistry at Delhi, north India. *Atmospheric Environment*, 2004, 38, 4215–4222.
- [24] R. Das, S.N. Das, V.N. Misra, Chemical composition of rainwater and dustfall at Bhubaneswar in the east coast of India. *Atmospheric Environment*, 2005, 39, 5908–5916.
- [25] G. Wagner, K. Steele, M. Peden, Dew and Frost Chemistry at a Midcontinental Site, United States. *J. Geophys. Res.* 1992, 97, 20591–20597.
- [26] J. Rodier, L'analyse de L'eau: Eaux Naturelles, Eaux Résiduaire, Eau de Mer. 8^{ème} édition. Dunod, Paris, 1996, 1365p.
- [27] W.C. Keene, A.P. Pszeny, J.N. Galloway, M.E. Hawley, Sea salt corrections and interpretations of constituent ratios in marine precipitation. *Journal of Geophysical Research*, 1986, 91, 6647–66 58.
- [28] U.C. Kulshrestha, A.K. Sarkar, S.S. Srivastava, D.C. Parashar, Investigation into atmospheric deposition through precipitation studies at New Delhi (India). *Atmospheric Environment*, 1996, 30 (24), 4149–4154.
- [29] M. Al Obaidy, H. Himanshu Joshi, Chemical composition of rainwater in a tropical urban area of northern India. *Atmospheric Environment*, 2006, 40 6886–6891.
- [30] J.P. Riley, R. Chester, *Introduction to Marine Chemistry*. Academic Press, London and New York, 1971.