Estimation of dew resources in Valparaíso, Chile, using available meteorological data and semi analytical modeling

Estimación de recursos de rocío en Valparaíso, Chile, utilizando datos meteorológicos disponibles y modelación semianalítica

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ABSTRACT

In arid regions, dew can provide a potential supplementary water resource, which is relatively meager compared to actual rainfall but with a more regular distribution of events throughout the year, even during periods of drought. Thus, quantifying the dew potential in different locations is of utmost interest. This study aims to quantify the available dew resources in the coastal Valparaíso region, using a semi-analytical model proposed by Beysens in 2016, depending on four meteorological data: air and dew temperatures, wind velocity, and cloud coverage. These data were obtained from the Chilean Meteorological State Service website for the Rodelillo site, which has one value per hour. Three complete years were considered, from 2019 to 2021, showing total amounts of rain precipitation ranging from 110 to 400 mm, with rain mainly concentrated during winter. Dew estimations were found to be quite regular during the year, with an average of 2.2 mm per month, and showing a positive evolution from one year to another, with total amounts respectively equal to 27 mm (2019), 30 mm (2020), and 34 mm (2021). This interesting result indicates that the region of coastal central Chile presents a high potential for dew harvesting and a resource which, contrary to rain, whose amplitude diminishes continuously, is likely to increase.

Keywords: Alternative water resource, dew harvesting, coastal zone, semi analytical modeling.

RESUMEN

En las regiones áridas, el rocío puede proporcionar un recurso hídrico potencial adicional, generalmente pequeño en comparación con la cantidad de lluvia, aunque con una distribución más regular durante el año, incluso durante la estación seca. Por tanto, es de interés cuantificar el potencial de rocío en diferentes ubicaciones. El objetivo de este estudio es cuantificar los recursos de rocío disponibles en la región costera de Valparaíso, mediante un modelo semianalítico, propuesto por Beysens en 2016, en función de cuatro datos meteorológicos: temperaturas del aire y de rocío, viento y nubosidad. Estos datos fueron obtenidos del sitio web del servicio meteorológico estatal de Chile, para el sitio Rodelillo con un valor por hora. Se consideraron tres años completos, 2019 a 2021, mostrando cantidades totales de precipitación pluvial que oscilaron entre 110 y 400 mm, concentrándose la lluvia mayormente durante el período invernal. Las estimaciones de rocío fueron más regulares a lo largo del año, con una media de 2,2 mm por mes, y comparables de un año a otro con cantidades totales respectivamente iguales a 27 mm (2019), 30 mm (2020) y 34 mm (2021). Este interesante resultado indica que la región de la costa central de Chile presenta un alto potencial para la recolección de rocío, un recurso que, a diferencia de la lluvia cuya amplitud disminuye continuamente, es probable que aumente.

Palabras clave*: Recurso hídrico alternativo, recolección de rocío, zona costera, modelación semianalítica.*

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INTRODUCTION

Dew has been systematically studied from a meteorological point of view since the 1950s [1] and from a physical point of view since the 1990s [2]. This phenomenon corresponds to the condensation into liquid droplets of water vapor on a substrate. A key point is the drop interaction through drop fusion or coalescence, leading to the possibility of a water flow through gravity and to the production of clean water by "*atmospheric wells*" [3]. First, dew collection measurements were carried out in the early 1990s in Sweden and Tanzania by Nilsson [4] using a 1.44 m^2 panel and later using a small radiative condenser (1×0.3 m^2) in Grenoble (France) [5]. In the early 2000s, a larger condenser (10×3 m^2) was then successfully tested in Ajaccio (Corsica, France) with a maximum yield of 0.38 mm•day^{-1}, demonstrating the interest of this approach to provide potential complementary water resources [6]. This important result triggered the following tests, conducted in different places around the world such as India [7], Morocco [8], humid tropical islands [9], Azerbaijan [10], or, more recently, in the northern part of Chile [11], China [12] and Syria [13], illustrating that dew harvesting can be applied in widely different conditions, even in arid places with low rain amount. In India and Chile, galvanized iron roofs have been used as condensers, indicating that dew can be harvested using current materials widely available [7], [11]. In addition, thermal insulation and Infra-Red (IR) radiative additive white painting have increased water recollection by up to 40%, bringing additional interest toward the realistic feasibility of dew resources [14]. Dew recollection has also been successfully tested in urban environments, showing that approach is not restricted to remote places [15].

Despite all these successes, a key point remains that dew resource evaluation should be conducted before any investments, such as roof installation. This evaluation is usually made using a small dew condenser for at least a year. This step is simplified by Daniel Beysens, who proposed in 2016 a semi-analytical model to estimate dew yield worldwide from a few meteorological data values [16]. This model has been validated using previous experimental studies and allows for building maps of available dew resources [3]. The same model can map future evolution [17], [18]. Even if the cumulative dew water yield remains usually modest compared to the average annual rainfall, dew occurs far more frequently during the year. It can be available during the dry season. Moreover, dew water is generally potable, especially in rural locations, and therefore, dew can be considered a viable water resource supplement in the context of adaptation to climate change [19], [20]. This study aims to quantify the available dew resources in the Valparaíso region (Chile) using Beysen's model and available meteorological data.

MATERIALS AND METHODS

Valparaíso region, in central Chile, exhibits a variety of geographical sites: ocean coast, low and high cordillera, river, forest, and open dry spaces. This first approach considers one place close to Valparaíso city, associated with reliable meteorological data.

Semi analytical model

The model proposed by Beysens in 2016 will be used as a reference [16]. This model, valid for planar dew collectors, is based on laboratory experiments where it is established that heat losses with the surrounding air are the dominant parameter that limits dew condensation. The analytical formula depends on the altitude H (in km) and four meteorological data: air and dew temperatures, respectively denoted T_a and T_d (in ºC), wind velocity denoted V (in m•s^{-1}), and cloud coverage denoted N (in okta). The dew yield in mm•day^{-1} [16] is given by equation (1).

$$\left(\frac{dh}{dt}\right)_1 = \begin{cases} 0.37 * \left[1 + 0.204323H - 0.0238893H^2 - \left\{18.0132 - 1.04963H + 0.21891H^2\right\} * 10^{-3} T_d\right] \\ * \left(\frac{T_d + 273.15}{285}\right)^4 * \left(1 - \frac{N}{8}\right) + 0.06 * \left(T_d - T_a\right) * \left(1 + 100 * \left\{1 - \exp\left[-\left(\frac{V}{V_0}\right)^{20}\right]\right\}\right) & \text{if positive} \\ 0 & \textit{if negative} \end{cases} \quad (1)$$

With the cut off velocity V_0 equal to 4.4 m•s^{-1}. These parameters are usually taken before sunrise, typically at 6 AM, when the dew phenomenon peaks, mainly due to the lowest night temperature, to obtain one yield value per day. However, the same formula can be used for each measurement, every 15 minutes or every hour, for example, to obtain instantaneous yield values. The day value is then obtained using the integral over the 24 hours. The first three parameters, wind velocity, air, and dew temperature, can be routinely automatically obtained using meteorological stations. However, cloud coverage is usually estimated by an operator observing the sky in terms of how many eighths of the sky are covered in cloud, ranging from 0 oktas (clear skies) to 8 oktas (completely overcast). In airport meteorological stations, okta is often measured only during operation hours. Technically, the meteorological data will be first stored in a database; then, the dew hourly and daily yield will be computed using the model. Note that the dew yield is taken as zero when rain is measured.

Dataset

Meteorological data were obtained from the Chilean Meteorological State service site - Climate Services of the station Rodelillo, Ad. (Station code: 330007, Latitude: -33.065277, Longitude: –71.556388 [21]). The station is located over a hill close to the coast, at an altitude of 330 m, close to the local airport 6 km from the center of Valparaíso city, as shown in Figure 1.

The recollected variables from the available data correspond to dew temperature, denoted T_d (in ºC), dry air temperature, denoted T_s (in ºC), mean surface wind velocity, denoted *ff* (in kt), and the amount of sky covered, denoted N (in okta). Examples of recollected variables are shown in Figure 2. Note that the dew temperature is when the water vapor in the air begins to condense, producing dew, mist, and others. Likewise, dry air temperature is also called air temperature or dry bulb temperature. Medium surface wind speed is measured at 10 m in height. The amount of sky covered corresponds to the total number of clouds covering the sky, estimated by an operator observing the sky. The data was collected for each hour and gathered by months. The missing data, typically N overnight, were replaced by the mean value of the closest hours. Wind velocity is obtained in m•s^{-1} using the unit conversion relation 1 kt = 0.5144 m•s^{-1}. The data were collected for three complete years: 2019, 2020 and 2021. The hourly rain amount is also recollected from the same data [21] to compare with the estimated dew amounts.

Figure 1. Station location [21].

	Date	Hour (UTC)	Td (°C)	Ts (°C)	ff (kt)	N (key)
0	2021-12-01	00:00:00	9.1	12.8	5.0	0
1	2021-12-01	01:00:00	8.6	11.3	1.0	NaN
2	2021-12-01	02:00:00	8.6	10.1	0.0	NaN
3	2021-12-01	03:00:00	8.3	9.9	0.0	NaN
4	2021-12-01	04:00:00	8.4	9.7	0.0	NaN
...	...	...	...	...	...	...
713	2021-12-31	19:00:00	8.6	25.6	12.0	0
714	2021-12-31	20:00:00	6.6	25.5	10.0	0
715	2021-12-31	21:00:00	6.3	23.2	8.0	0
716	2021-12-31	22:00:00	5.8	20.4	15.0	0
717	2021-12-31	23:00:00	7.1	16.8	18.0	0

718 rows × 6 columns

Figure 2. Example of recollected variables from the meteorological website, for December 2021.

RESULTS

First, an example of hourly dew yield was obtained using equation (1) with the 4 data of interest, i.e., air and dew temperatures, cloud covering, and wind velocity. Those data are illustrated for the first week of December 2021 (Figure 3). The dashed rectangle indicates a strong dew during a cold night without clouds and wind (day 2). The dew yield for the next day is inferior due to the partly cloudy sky ($N = 4$). The remaining days, dew yield is non-existent or minimal due to high air temperature (day 4), cloudy sky (days 5 to 7), or strong wind (day 6). The dew yield is first calculated hourly and then gathered daily and monthly. Similar scales are considered for rain to facilitate comparison between both resources.

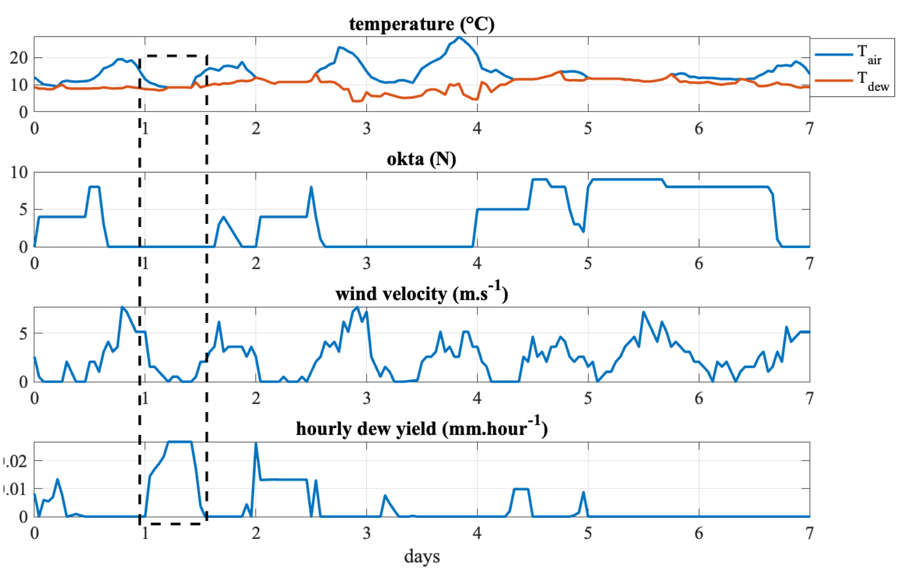

Figure 3. Example of data and associated hourly dew yield obtained with equation (1) during the first week of December 2021.

Daily and monthly amounts of rain (actual measurement) and dew (estimation obtained using the model and data described) are shown for the three years in Figure 4a (daily amount) and Figure 4b (monthly amount). Three complete years were considered, showing different total amounts of rain precipitation: dry year (2019, 110 mm), wet year (2020, 400 mm), and median year (2021, 210 mm), with rain mainly concentrated during the winter period (June to September). However, dew estimations were found to be more regular during the year, with an average of 2.2 mm per month, and comparable from one year to another with total amounts respectively equal to 27 mm (2019), 30 mm (2020), and 34 mm (2021). The annual dew to rain ratio ranged from 14% to 25% (Figure 5). These values are more significant than the usual 5-10% ratios observed in other worldwide locations [16]. This difference may be due to the high coastal humidity and relatively low annual rainfall. However, this ratio can be much larger (over 500%) during the dry season (Figure 4b).

DISCUSSION

Annual dew yield and dew-to-rain ratio have been obtained in different locations worldwide. Figure 6 shows some of these locations with annual dew yield from 2 to 32 mm. The study locations include mountain, semi-arid, and coastal areas. The maximum dew yield is around 30 to 32mm, mainly in coastal and some semi-arid areas. The minimum dew yield

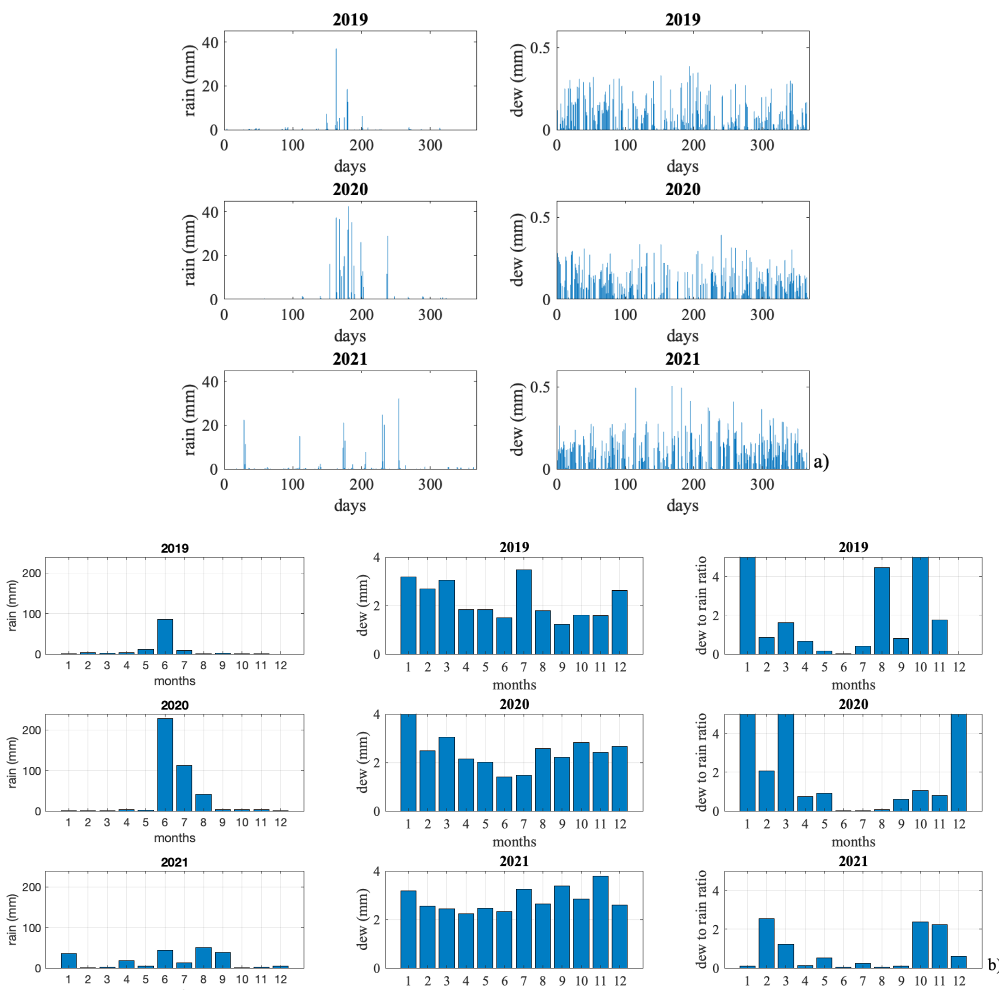

Figure 4. Daily a) and monthly b) actual rain (left column) amounts and dew (middle column) amounts and dew to rain ratio (right column) obtained using equation (1).

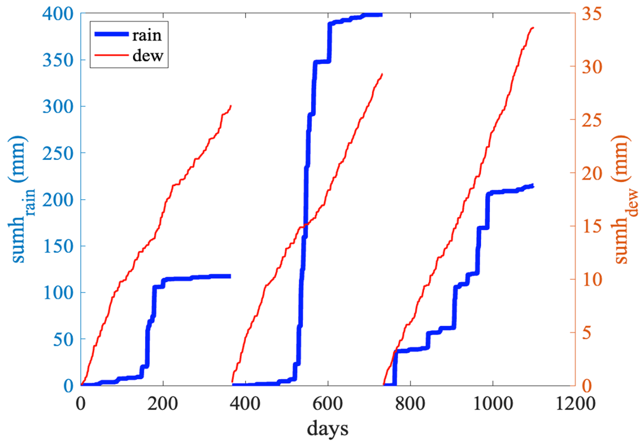

Figure 5. Cumulative amount of rain (bold blue line) and dew (thin red line) in mm for the three consecutive years (2019, 2020, and 2021).

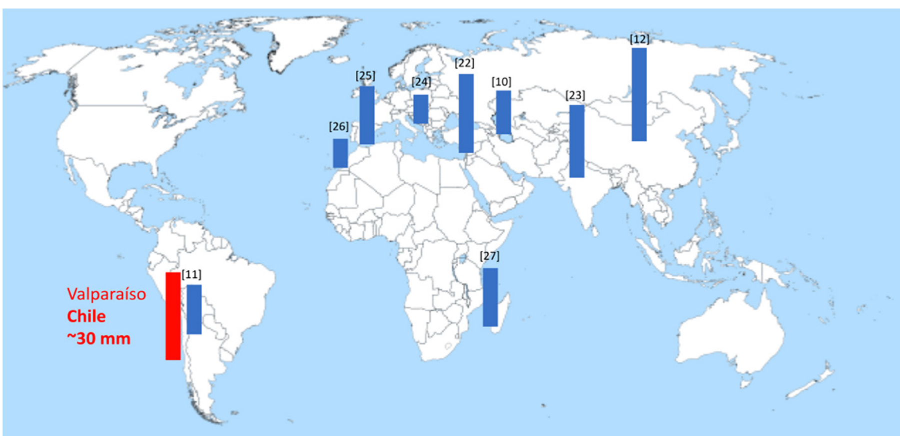

Figure 6. Annual dew yield measured in different locations worldwide, ranging from 2 to 32 mm.

is around 2 to 7mm in mountain and arid coastal areas. Table 1 compares the annual dew yield and dew-to-rain ratio obtained in these locations. One has to note that much larger ratios, higher than 500%, are found when considering the ratio during the dry season (Figure 4).

The main characteristics of Valparaiso's climate must be considered to understand the formation of dew and the extent of precipitation in Valparaiso. Several factors indeed control dew formation and rainfall.

Concerning dew, one observes in the present study that dew forms quite regularly, in contrast to rain; this is true even during the rainy season, where only a slight decrease is observed due to the increase of rainy, non-dewy days (Figure 5). Indeed, dew formation is mainly influenced by the atmosphere's relative humidity. The larger the RH, the closer the dew point temperature to air temperature and the higher the dew yield according to equation (1). This high humidity in Valparaíso over the years is due to several factors. One is the proximity to the Pacific Ocean. The constant presence of the sea provides a steady source of moisture to the air. Another is the Humboldt Current that flows northward along the coast of Chile, present during most of the year. This cold ocean current cools the air above it, increasing

Table 1. Comparison of annual dew yield and dew to rain ratio obtained in previous studies conducted in different worldwide locations.

Reference	study location	annual dew yield	annual dew to rain ratio
D. Beysens *et al.* 2009 [24]	mountain, South Croatia (Komiza) coastal, South Croatia (Zadar)	2-11 mm 9-21 mm	1.6% 11.7%
I. Lekouch *et al.* 2012 [26]	arid coastal, Southern Maroc (Id Ouassaksou) (Mirleft)	7 mm 18 mm	44% 40%
D. Meunier, D. Beysens 2016 [10]	semi-arid, Baku, Azerbaijan	15 mm	18%
D. Carvajal *et al.* 2018 [11]	semi-arid, Coquimbo region, Chile	~17 mm	8,2%
J.F. Maestre-Valero *et al*. 2011 [25]	semi-arid, Southern Spain	21 mm	6.6%
A. Rasoafaniry *et al.* 2024 [27]	semi-arid, south west Madagascar	10-30 mm	3-4%
G. Sharan 2011 [23]	semi-arid, Northwest India	20-30 mm	~10%
M. Karaeen, M. Odeh 2016 [22]	semi-arid, West Bank, Palestine	27 mm	8%
Z. Jia *et al.* 2019 [12]	semi-arid, Shaanxi Province, China	32 mm	5,6%
This study	coastal, Valparaíso region, Chile	~30 mm	14-25%

the relative humidity. In addition, Valparaíso experiences moderate temperatures throughout the year due to its very mild Mediterranean climate (Köppen classification Csb). Concerning the wind regime, winds blowing from the ocean (westerly winds) bring moist air to the coastal region, maintaining high humidity levels. These winds are more prevalent during the winter, enhancing the humidity during the wet season. Also, the coastal hills and valleys around Valparaíso influence local wind and moisture patterns, trapping moist air in some areas and affecting relative humidity. The presence of high-pressure systems off the coast can trap moisture near the surface, maintaining higher humidity levels.

The occurrence of rain corresponds to the Valparaiso Mediterranean climate, characterized by rainy winters and dry summers (Figure 4). This pattern is typical of coastal regions in central Chile, influenced by the subtropical high-pressure systems. The cold Humboldt Current brings cooler, moist air, leading to coastal fog and drizzle, particularly in winter. The proximity to the Andes Mountains plays a crucial role. The mountains create a rain shadow effect, where moist air rises, cools, and precipitates on the windward side (closer to the mountains), leaving the coastal areas, including Valparaíso, relatively drier. The vast Pacific Ocean moderates the temperature and provides a source of moisture. Oceanic influences are significant, especially during El Niño and La Niña events, which can alter typical weather patterns and impact rainfall. The El Niño-Southern Oscillation (ENSO) events can significantly increase rainfall in Valparaíso. El Niño leads to warmer ocean temperatures and altered atmospheric circulation, often resulting in heavier and more frequent rains. During the winter, westerly winds bring moist air from the Pacific Ocean to the coast, increasing precipitation. These winds are part of the larger atmospheric circulation patterns that affect the region.

Understanding these factors provides a comprehensive view of the climatic dynamics affecting dew and rainfall in Valparaíso. It can be used to tentatively predict the dew and rain trends for future years in a context of global change. In many regions of the world, dew and rain are seen to decrease [17], [19], [28]-[32], an effect attributed to climate change. Significant trends were found in calculated dew yields in the world during the time period 1979-2012 [17]. The trends were positive and negative, with values evolving in the range of ± 15%. The present three years of study show a positive trend, but more data is needed to assess this trend.

The continuous decrease of rainfalls in Valparaiso (Figure 7), observed here during the period 1900-2021, can also be attributed to climate change. However, it remains very challenging to understand the situation as many parameters are present. As

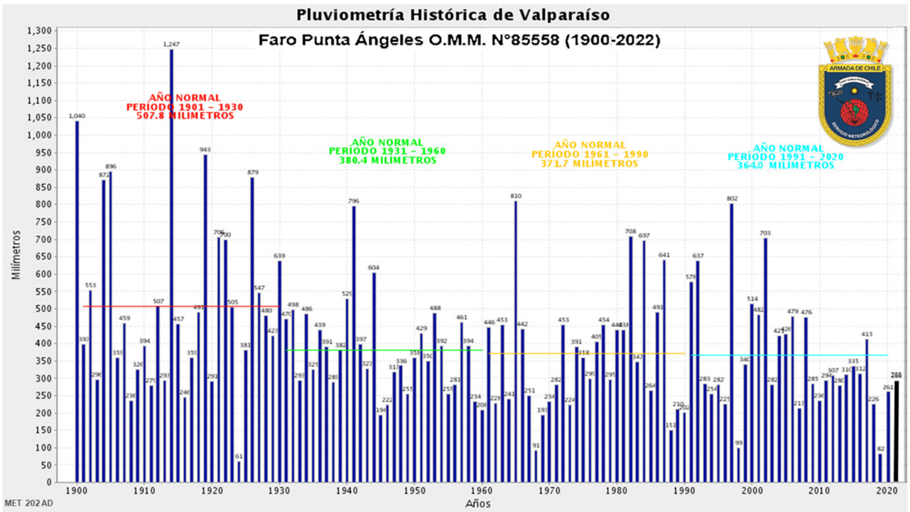

Figure 7. Rain evolution in Valparaiso in the period 1900-2022 [34]. The place "faro Punta Angeles" is located 2 km west from the Rodellilo airport (Figure 1).

far as ENSO is concerned, climate models [33] suggest that extreme El Niño events might become more frequent with global warming as the sea surface temperatures rise, which may enhance the atmospheric conditions necessary for more powerful El Niño events. The impacts of these events may become more pronounced in certain regions. For instance, areas that typically experience increased rainfall during El Niño might see even more extreme precipitation events, while regions prone to droughts could experience more severe dry conditions.

Further works should precise this point by extracting, as it was done for the Mediterranean basin [28] and northwest Africa [18], the meteorological data for years up to 2100 from the representative low and high emissions concentration pathway scenarios (e.g., low global warming RCP 2.6 and high global warming RCP8.5). These data allow dew and rain yields to be estimated with exactness.

CONCLUSION

The preliminary results obtained in this study at a Valparaíso region reveal that Chile's central coastal region has a significant potential for dew harvesting. In contrast to rain, which occurs mainly in winter, dew forms at nearly the same rate throughout the year. The contribution of dew to the water balance as measured by the dew/rain ratio is significant, 14-25%, as a yearly mean ranging from 100% to more than 500% during the summer dry season. These promising results should be confirmed by dew measurements on small or large condensers such as galvanized roofs. Although rain decreases with the years, the present study suggests an increase, although a three-year study is not enough to assess a trend. Further studies must consider several locations, years, and climate change scenarios to define a possible outcome.

REFERENCES

[1] J.L. Monteith, "Dew," *Quarterly Journal of the Royal Meteorological Society*, vol. 83, pp. 322-341, 1957, doi: 10.1002/qj.49708335706.

[2] D. Beysens, "The formation of dew," *Atmospheric Research*, vol. 39, pp. 215-237, 1995, doi: 10.1016/0169-8095(95)00015-J.

[3] M. Tomaszkiewicz, M.A. Najm, D. Beysens, I. Alameddine, and M. El-Fadel, "Dew as a sustainable non-conventional water resource: A critical review," *Environmental Reviews*, vol. 23, pp. 425-442, 2015, doi: 10.1139/er-2015-0035.

[4] T. Nilsson, "Initial experiments on dew collection in Sweden and Tanzania," *Solar Energy Materials and Solar Cells*, vol. 40, no. 1, pp. 23-32, 1996, doi: 10.1016/0927-0248(95)00076-3.

[5] D. Beysens, I. Milimouk, V. Nikolayev, M. Muselli, and J. Marcillat, "Using radiative

cooling to condense atmospheric vapor: A study to improve water yield," *Journal of Hydrology*, vol. 276, pp. 1-11, 2003, doi: 10.1016/S0022-1694(03)00025-8.

[6] M. Muselli, D. Beysens, J. Marcillat, I. Milimouk, T. Nilsson, and A. Louche. "Dew water collector for potable water in Ajaccio (Corsica island, France)," *Atmospheric Research*, vol. 64, pp. 297-312, 2002, doi: 10.1016/S0169-8095(02)00100-X.

[7] G. Sharan, D. Beysens, and I. Milimouk-Melnytchouk, "A study of dew water yields on galvanized iron roofs in Kothara (north-west India)," *Journal of Arid Environments*, vol. 69, pp. 259-269, 2007, doi: 10.1016/j.jaridenv.2006.09.004.

[8] I. Lekouch, M. Muselli, B. Kabbachi, J. Ouazzani, I. Melnytchouk-Milimouk, and D. Beysens, "Dew, fog, and rain as supplementary sources of water in south-western Morocco," *Energy*, vol. 36, pp. 2257-2265, 2011, doi: 10.1016/j.energy.2010.03.017.

[9] O. Clus, P. Ortega, M. Muselli, I. Milimouk, and D. Beysens, "Study of dew water collection in humid tropical islands," *Journal of Hydrology*, vol. 361, pp. 159-171, 2008, doi: 10.1016/j.jhydrol.2008.07.038.

[10] D. Meunier and D. Beysens, "Dew, fog, drizzle and rain water in Baku (Azerbaijan)," *Atmospheric Research*, vol. 178-179, pp. 65-72, 2016, doi: 10.1016/j.atmosres.2016.03.014.

[11] D. Carvajal, J.-G. Minonzio, E. Casanga, J. Muñoz, A. Aracena, S. Montecinos, and D. Beysens, "Roof-integrated dew water harvesting in Combarbalá, Chile," *Journal of Water Supply: Research and Technology-Aqua*, vol. 67, pp. 357-374, 2018, doi: 10.2166/aqua.2018.174.

[12] Z. Jia, Z. Zhao, Q. Zhang, and W. Wu, "Dew yield and its influencing factors at the western edge of Gurbantunggut desert, China," *Water*, vol. 11, no. 4, Art. no. 733, 2019, doi: 10.3390/w11040733.

[13] M. Khalil, A. Kara-Ali, and M. Asaad, "Potential of harvesting water from fog and dew water over semi-arid and arid regions in Syria," *Water Supply*, vol. 22, no. 1, pp. 874-882, 2021, doi: 10.2166/ws.2021.229.

[14] J. Trosseille, A. Mongruel, L. Royon, and D. Beysens, "Effective substrate emissivity during dew water condensation," *International Journal of Heat and Mass Transfer*, vol. 183, 122078, 2022, doi: 10.1016/j.ijheatmasstransfer.2021.122078.

[15] D. Beysens, A. Mongruel, and K. Acker, "Urban dew and rain in Paris, France: Occurrence and physico-chemical characteristics," *Atmospheric Research*, vol. 189, pp. 152-161, 2017, doi: 10.1016/j.atmosres.2017.01.013.

[16] D. Beysens, "Estimating dew yield worldwide from a few meteo data," *Atmospheric Research*, vol. 167, pp. 146-155, 2016, doi: 10.1016/j.atmosres.2015.07.018.

[17] M. Muselli and D. Beysens, "Mapping past, present and future dew and rain water resources for biocrust evolution in southern Africa," *Journal of Hydrology and Hydromechanics*, vol. 69, no. 4, pp. 400-420, Art. no. 3921, 2021, doi: 10.2478/johh-2021-0030.

[18] M. Muselli, I. Lekouch, and D. Beysens, "Physical and chemical characteristics of dew and rain in north-west Africa with focus on Morocco: Mapping past and future evolution (2005-2100)," *Atmosphere*, vol. 13, no. 12, Art. no. 1974, 2022, doi: 10.3390/atmos13121974.

[19] D. Beysens, *Dew water*, Gistrup, Denmark: River Publishers, 2018.

[20] K.F. Kaseke and L. Wang, "Fog and dew as potable water resources: Maximizing harvesting potential and water quality concerns," *GeoHealth*, vol. 2, pp. 327-332, 2018, doi: 10.1029/2018GH000171.

[21] DGAC Chile, "Ficha de la Estación. Metadatos disponibles en el Sistema SACLIM," climatologia.meteochile.gob.cl. [En línea]. Disponible en: https://climatologia.meteochile.gob.cl/application/informacion/fichaDeEstacion/330007

[22] M. Karaeen and M.W. Odeh, "Dew Harvesting from Atmosphere to Supply Water from the Mid Heights in the West Bank of Palestine," in *4th International Conference on Energy and Environmental Protection in Sustainable development* (ICEEP), Hebron, Palestine, April 6-7, 2016, 38, doi: 10.13140/RG.2.1.3540.1842.

[23] G. Sharan, "Harvesting Dew with Radiation Cooled Condensers to Supplement Drinking

Water Supply in Semi-arid Coastal Northwest India," *International Journal for Service Learning in Engineering*, vol. 6, pp. 132-152, 2011, doi: 10.24908/ijsle.v6i1.3188.

[24] D. Beysens, I. Lekouch, M. Mileta, I. Milimouk, and M. Muselli, "Dew and Rain Water Collection in South Croatia," *International Journal of Environmental Science and Engineering*, vol. 92, no. 4, pp. 455-463, 2009, doi: 10.1016/j.atmosres.2009.01.004.

[25] J.F. Maestre-Valero, V. Martínez-Alvarez, A. Baille, B. Martin-Górriz, and B. Gallego-Elvira, "Comparative analysis of two polyethylene foil materials for dew harvesting in a semi-arid climate," *Journal of Hydrology*, vol. 410, pp. 84-91, 2011, doi: 10.1016/j.jhydrol.2011.09.012.

[26] I. Lekouch, K. Lekouch, M. Muselli, A. Mongruel, B. Kabbachi, and D. Beysens, "Rooftop dew, fog and rain collection in southwest Morocco and predictive dew modeling using neural networks," *Journal of Hydrology*, vol. 448-449, pp. 60-72, 2012, doi: 10.1016/j.jhydrol.2012.04.004.

[27] A. Rasoafaniry, M. Muselli, and D. Beysens, "Dew and Rain Evolution from Climate Change in Semi-Arid South-Western Madagascar between 1991 and 2033 (Extrapolated)," *Atmosphere*, vol. 15, no. 7, 784, 2024, doi: 10.3390/atmos15070784.

[28] M. Tomaszkiewicz, M. Abou Najma, D. Beysens, I. Alameddine, E. Bou Zeid, and M. El-Fadel, "Projected climate change impacts upon dew yield in the Mediterranean basin," *Science of the Total Environment*, vols. 566-567, pp. 1339-1348, 2016, doi: 10.1016/j.scitotenv.2016.05.195.

[29] N. Atashi, D. Rahimi, B.M. Goortani, J. Duplissy, H. Vuollekoski, M. Kulmala, T. Vesala, and T. Hussein, "Spatial and temporal investigation of dew potential based on long-term model simulations in Iran," *Water*, vol. 11, no. 12, 2463, 2019, doi: 10.3390/w11122463.

[30] N. Atashi, D. Rahimi, M. Al Kuisi, A. Jiries, H. Vuollekoski, M. Kulmala, T. Vesala, and T. Hussein, "Modeling long-term temporal variation of dew formation in Jordan and its link to climate change," *Water*, vol. 12, no. 8, 2186, 2020, doi: 10.3390/w12082186.

[31] M. Lal, "Global climate change: India's monsoon and its variability," *Journal of Environmental Studies and Policy*, vol. 6, pp. 1-34, 2003.

[32] Y.Y. Loo, L. Billa, and A. Singh, "Effect of climate change on seasonal monsoon in Asia and its impact on the variability of monsoon rainfall in Southeast Asia," *Geoscience Frontiers*, vol. 6, pp. 817-823, 2015, doi: 10.1016/j.gsf.2014.02.009.

[33] S.J. Perry, S. McGregor, A.S. Gupta, and M.H. England, "Future changes to El Niño-Southern Oscillation temperature and precipitation teleconnections," *Geophysical Research Letters*, vol. 44, no. 20, pp. 10.608-10.616, 2017, doi: 10.1002/2017GL074509.

[34] Servicio Meteorológico de la Armada de Chile. [En línea]. Disponible en: http://web.directemar.cl/met/jturno/pluvio/graficos/graficos_pluviometrias_historicas.png